SATELLITE COMMUNICATIONS

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[illegible] answers to exercises are given with justification wherever necessary.

SATELLITE COMMUNICATIONS

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Dedicated to my parents
for their inspiration

PREFACE TO THE FOURTH EDITION

The third edition of the book brought out in 1995 included two new chapters covering at length different areas in which satellites find application and detailed technical information on satellites and satellite launch vehicles. It is indeed a matter of great satisfaction to note that the third edition was very well received by the students of various levels. We have been regularly receiving letters containing suggestions. We are glad that the author has put in a great effort to implement the suggestions within the scope of the text. The fourth edition, again an enlarged one, is before you within an year of the release of the third edition.

The present edition contains two new chapters. The first contains a large number of **solved numerical problems** related to different aspects of satellite communication engineering and the second basically an **illustrated glossary** of satellite relevant terms, definitions and concepts. To make the book more meaningful from examination viewpoint, a separate section titled ***Self Assessment Questions*** containing Multichoice Questions, Fill in the blanks and True/False statements, all with answers, has been included towards the end. This new material has also been written by Mr. A K. Maini

We would continue to look forward to any critical comments, etc. form our valued readers.

KHANNA PUBLISHERS

A WORD

This Edition is result of valuable suggestions, criticism, comments from Teachers and Students.

The Publishers and the Author welcome your valued comments and suggestions on any facet of this book and the related topics. These will be acknowledged gratefully. Please write at the following address:

The Technical Editor
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CONTENTS

ONE

Principles Of Satellite Communication

1.1. Evolution and Growth of Communication Satellites

The idea of communication through a satellite, in particular with a synchronous satellite was conceived by Arthur C. Clarke, a famous British science fiction writer in 1945[1]. Clarke had already pointed out that a satellite [illegible]

[illegible]

satellites and thus reliable communication between any two points in the world [illegible]

[illegible] per powers [illegible] was a kind [illegible] AT and T, [illegible]

[illegible]

May 7, 1963 established the basis of modern technique of communication satellite. The TELSTAR I [illegible]

ranging from instruments with a small capacity (240 voice circuits or one television channel) to those with a huge capacity (12500 voice circuits and two television channels) and covering three regions-the Atlantic, Pacific and Indian Oceans. Thus a new era of Communication via satellite (satellite Communication) had begun and now over hundreds of geostationary satellites of different countries of the world are in the service. This is expected to grow in a very large number in near future[4,5].

1.2. Synchronous Satellites

As already mentioned the synchronous satellites also called the

afford to its own terminal, and the rf spectrum required for the system can be readily shared with other services. There are a few problems with these synchronous communication satellites, namely the time delay, in connection with telephony and the establishment of the synchronous orbit.

The synchronous satellites used for communication are widely called the communication satellites. These satellites are classified in terms of their

in terms

tical, etc

rimental

Cuba. There are over 2 dozen countries including India which have their domestic satellite systems either operational or in advanced planning stages. These satellites have special shaped antenna beams to provide domestic

Military satellites are principally those of super powers. A Typical example is that of US's *Defence Satellite Communications system* (*DSCS*) which constitues a series of satellites to provide worldwide military communications. The circuit capacities of military satellites are modest

data relay satellite of special purpose technology satellite incoln Laboratories (LES), the European Space Agency Orbital test satellite (OTS) and the Japanese (ECS) etc. A variety of experiments concerning with communication technology and space propagation/communication at various frequency bands have been carried out by these experimental satellites.

1.3. International Regulation and Frequency Coordination

International Frequency Registration Board (IFRB), International Radio Consultative Committee (CCIR) and the International Telegraph and Telephone Consultative Committee (CCITT). The General Secretariat is located in Geneva. It is responsible for the executive management and technical cooperation. The IFRB is responsible for recording frequencies and orbital positions and for advising member countries on operation of the maximum practical number of radio channels in portions of the spectrum where harmful

to telegraphy and telephony and for adopting reports and recommendations.

broadcasting, earth exploration, space research, meteorological, space

1.4. Satellite Frequency Allocations and Band Spectrum

There are six frequency bands that have been allocated for the use with satellite communications. Table 1.1 gives these bands. It may be noted that in addition to these bands given in Table 1.1, millimetre waves in the frequency ranges 40 – 300 GHz are also allocated for satellite communication purposes. [illegible] MHz, 7450 – 7550 MHz.

Table 1.1 Frequency Bands for Satellite Communication

Band	*Downward Bands MHz*	*Uplink Bands MHz*
Uhf – Military	250 – 270 (Approx)	292 – 312 (Approx)
C Band – Commercial	3700 – 4200	5925 – 6425
X Band – Military	7250 – 7750	7900 – 8400
Ku Band – Commercial	11700 – 12200	14000 – 14500
Ka Band – Commercial	17,700 – 21200	27500 – 30,000
Ka Band – Military	20200 – 21200	43500 – 45500

Table 1.2. Frequency Allocations for Fixed Satellite Service and Broadcasting Satellites

Frequency	*Fixed Satellite Service*	*Broadcasting Satellites*
2500 – 2535 MHz	Down Region II and III	Down
2535 – 2655	Down Region II	Down
2655 – 2690	Up Region II and III	Down
3400 – 3700	Down	
3700 – 4200	Down	
4500 – 4800	Down	
5725 – 5850	Up Region I	
5850 – 5925	Up	
5925 – 7075	Up	
7250 – 7450	Down	
7450 – 7550	Down	
7900 – 8025	Up	
8025 – 8400	Up	
10.7 – 11.7 GHz	Down	Up Region I
11.7 – 12.1	Down Region II	Down Region I and III
12.1 – 12.2	Down Region II	Down

Table Cont'd

Frequency	*Fixed Satellite Service*	*Broadcasting Satellites*
12 2 —12 3	Down Region II	Down Region I & II
12 3—12.5		Down Region I & II
12.5—12 75	UP/Down	Down Region II
12.75—13.25	Up	
14 0—14.5	Up	
14 5—14 8		Up
17.3—17.7		Up
17.7—18.1		Up
18 1—18 6	Down	
18 6—18 8	Down	
18 8—20 2	Down	
20 2—21 2	Down	
22 5—23.0		Down Region II & III
27.0—27 5	Up Region II & III	
27.5—29.5		
29 5—31.0	Up	
37.5—39 5	Down	
39 5—40 5	Down	
40 5—42.5		Down
42.5—43.5	Up	Down
47.2—49.2		Up
49.2—50 2	Up	
50 4—51.4	Up	
71 0—75.5	Up	
81—84	Down	
84—86		Down
92—95	Up	
102—105	Down	
149—164	Down	
202—217	Up	
231—241	Down	
265—275	Up	

Table 1.3. Frequency Allocations for Mobile Satellite Service

Frequency	*Aeronautical Mobile*	*Maritime Mobile*	*General Mobile*
806-890 Mhz			Region II & III
1530-1535		Down, Shared	(limited use)
1535-1544		Down, Exclusive	
1544-1545			Down
1545-1559	Down, Exclusive		Down
1626.5-1645.5		Up, Exclusive	
1645.5-1646.5			Up
1446.5-1660 5	Up, Exclusive		
1660-1660 5	Up, Shared		
19.7-21 2 GHz			Down
29 5-31.0			Up
39 5-40 5			Down
43 5-47			Up
66.71			Up/Down
71-74			Up/Down
81-84			Up/Down
95-100			Up/Down
134-142			Up/Down
190-200			Up/Down
252-265			Up/Down

1.5. General and Technical Characteristics Of A Satellite Communication System

[illegible] of a satellite communication system [illegible] ... [illegible] down-link to the earth [illegible]

frequency spectrum in order to avoid the interference. The signal at the receiving earth station is processed to get back the baseband signal which is then sent to the user through a terrestrial network. Had there been no diffference [illegible]

On the guidelines of WARC - 1979 commercial communication satellites use a frequency band of 500 MHz bandwidth near 6 GHz for up-link transmissions and another 500 MHz bandwidth near 4 GHz for downlink transmission. Infact an uplink of 5.725 to 7.075 GHz and a downlink of 3.4 to 4.8 GHz is used. It may be noted that this 6/4 GHz band is also used in many countries for terrestrial communications (microwave links) and so the problem [illegible] to be looked into. The 500 MHz allocation

about 1500 analog FM voice circuits. If digital modulation is used, transponder data rates from 50 to 100 Mb are achievable. With the use of single side band [illegible] frequency reuse to increase the number of transponders in the 500 MHz allocated to them.

It should be of importance to note that 6/4 GHz bands have been the most popular because they offer the fewest propagation problems and historically RF components for these bands have been readily avilable. Rain attenuation is also not much serious at these bands. Sky noise is also low at 4 GHz and so it is possible to build [illegible] systems with lower noise temperature at 4 [illegible]

or 12.5 to 12.7 GHz. This frequency band is not yet congested and is hoped [illegible] advanced technology of satellite communicatjon has been focussed on these bands. Equipments on these frequency bands are in progress and experimental stage.

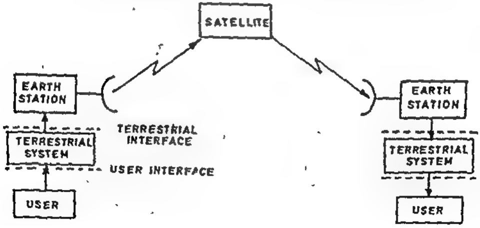


Fig. 1.1. General Structure of A Satellite Communication System

The basic block diagram of an earth station that transmits to and receives information from a satellite is shown in Fig 1.2. The base band signal from the terrestrial network enters the earth station at the transmitter after having processed (buffered, multiplexed, formatted etc) by a baseband equipment. After the encoder and modulator have acted upon the baseband signal, it is

converted to the uplink frequency. Then it is amplified and directed to the appropriate polarization port of the antenna feed. The signal received from the satellite is amplified in an LNA first and is then downconverted from the downlink frequency. It is then demodulated and decoded and then the original baseband signal is obtained. Critical components will often be installed redundantly with automatic switch over in the event of failure so that

intermodulation products generated in the transponder or earth terminal. It

satellites in space is 2° along the equatorial arc instead of 4°. The closer spacing has allowed twice as many satellites to occupy the same orbital arc and therefore now all the earth station antennas are designed to accommodate this spacing of 2°.

1.6. Advantages of Satellite Communication

Communication through satellite has several advantages and

only for specialized applications and the cascaded radio relays were limited

point to an arbitrary number of other points within its coverage area.

Some of the typical advantages of satellite communication are automatically derived when compared it with other kind of signal relay systems. Firstly the satellite relays are inherently wide-area broadcast, *i.e.* the *point- to-multipoint* whereas all the terrestrial relays are point-to-point. Secondly the satellite circuits can be installed rapidly. Once the satellite is in position, the earth stations can be installed and communication may be

is that the mobile communication can be easily achieved by satellite communications as it has a unique degree of flexibility in interconnecting mobile vehicles. Thus the satellite has become an alternative to short wave in this specialised area and has significant reliability advantages networks may interconnect mobile vehicles by cellular radios).

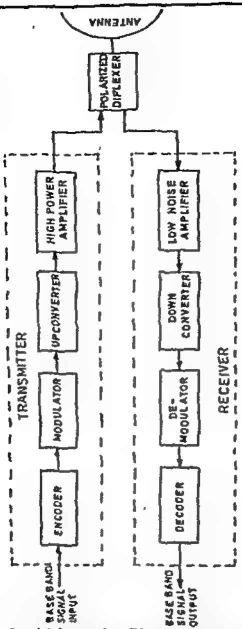


Fig. 1.2. Basic Block Diagram of an Earth Station.

The satellite communications has certain disadvantages as well. With the satellite in position the communication path between the terrestrial transmitter and the receiver is approximately 75000 km long. Since the velocity of em waves is 3×10^5 km/s, there is a delay of 1/4 seconds between the transmission

deployed in satellite communications, one may still feel the echo. The above time delay of 1/2 seconds also reduces the efficiency of satellite in data transmission and long file transfers when carried out over the satellites.

Satellite communication, however, has the economical advantages. The

wide-bandwidth signals across the ocean. For thin route remote area

Similarly for search, rescue and navigation efforts satellites offer the advantages which no other systems can offer.

1.7. Active and Passive Satellites

The difference between a passive and an active communication satellite

The most important comparison of the communication capability of active and passive satellites is the amount of power radiated toward the receiving ground stations by the satellite. Actually the communication capability of active systems with directional antennas rapidly becomes much greater than

modern communication satellites are active satellite systems. Now a days space qualiified reliable, long life electronic equipment are available and these have enhanced the capability of active satellite system.

1.8. Advent of Digital Satellite Communication

With the fast development in digital electronics technology, access techniques and possibility of expanded communication network, digital signalling techniques have been introduced in communication by satellites. [illegible]

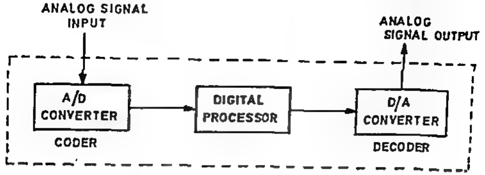
(LSI). Thus the digital transmission techniques have gained increased usage for satellite communication, microwave relay, and cable or waveguide transmission. In laser satellite communication too digital techniques have been successfully utilised.

Though the various digital modulation techniques will be discussed in later chapter, it may be mentioned here that in analog communication systems, [illegible]

stations with a small loss in transponder capacity. Further the system can quickly respond to traffic variations. A further increase in efficiency can be [illegible] nent and [illegible] onboard [illegible] use the digital communication techniques and such digital systems are capable of serving a mixture of large, medium and small earth stations with high efficiency. The recent technique of code division multiple access has allowed [illegible]

1.9. Modem and Codec

The equipment that carries out modulation (MOD) and demodulation (DEMOD) is called *modem*. Similarly the equipment responsible for carrying out coding and decoding is termed *codec*. These two devices are widely used [illegible] is used as an interface between [illegible] an important role in computer [illegible] ms. Codecs are used in digital television systems and normally consists of a pair of A/D [illegible] converter. It is a kind of black box digital device as shown in Fig [illegible]



Coder + Decoder = Codec

Fig. 1.3 Basic Block Diagram of Codec

1.10. Review Questions

1. What is a satellite and how does a communication satellite differ from a communication relay ?
2. *Explain the basic differences between an active and passive satellite systems.* Discuss their merits and demerits.
3. Prove that for covering the globe three communication satellites would be sufficient.
4. What is the difference between a geostationary satellite and a low altitude satellite ? Can a low altitude satellite be also used for communication purposes ? If not why ?
5. List various frequency bands being used in satellite communication. Compare *the advantages and disadvantages of different bands considering the effects* of propagation media.
6. Give the reasons as to why the uplink frequency is different than the down link frequency. Also mention the reasons for keeping uplink frequency higher than the downlink frequency.
7. What are the elements of satellite communication system ? Explain each with a suitable block diagram.
8 List various advantages and disadvantages of satellite communication. Give *the reasons that optical fibres inspite of being high bandwidth channel, Satellite* communication has an edge over it.
9. What are the advantages of a communication system that uses digital signal transmission ? Explain as to how the digital satellite communication has reduced the size of earth station ?
10. What are Modem and Codec ? Both are A/D and D/A converters but what makes the difference between the two ? Mention the areas of their applications.

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TWO

Communication Satellite Link Design

.1. Introduction

[illegible] e able to receive from the transmitting earth satellite and the power received om satellite repeater by the receiving earth station. This link budget [illegible]

[illegible]

The frequency allocations and band spectrum to be used in [illegible] are discussed already in Section 1.4. The optimum [illegible]

The cost of launching a satellite is extremely high and is now over $)0,000 per kg per launch with final positioning. This limits the size and weight f the satellite. This causes deployment of limited number of solar cells, and

limited size of satellite antennas. These size limitations combine to produce a [illegible] now larger satellites can be launched by space shuttle which in fact carries the satellite first into low earth orbit and then injects it into geostationary orbit. Space shuttle is capable of lifting nearly 30,000 kg into low earht orbit. Payloads as large as 2,000 kg in geostationary orbit are readily achievable and it is projected that payloads as large as 6,000 kg will be available when high energy upper stages are developed to transport satellites from low earth orbit to geostationary orbit. This inceased size in satellite will allow the use of larger diameter antennas with their narrow antenna beams which will careate the potential for generating several independent beams on board the satellite. When a particular region or a country is to be served, the antenna beam may be shaped to follow the contour of the region requiring coverage. This technique was firstly used in INTELSAT III and is now quite popular in domestic satellite systems.

2.2. General Link Design Equations

In satellite communications links design the important calculation is the power received by the receiving station (satellite receiver and the earth station).

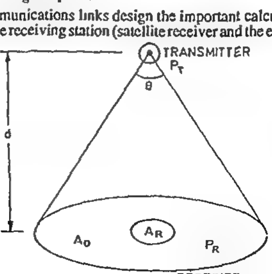

Fig 2.1. Geometry of a Simple Radio Link

This calculation is similar to that of the ...

is characteriz...
temperature ...
temperature T...
illuminates an...
receiver is d. ...
transmitted pc...
given by

$$P_R = P_T A_R / A_0 \quad ...(2.1)$$

The directivity of antenna is described by its gain as

$$G_T = \frac{4\pi d^2}{A_0} \quad ...(2.2)$$

which is actually the ratio of the area illuminated by an isotropic antenna to that illuminated by the antenna in question. From Eqs (2.2 and (2.1), one gets

$$P_R = P_T G_T A_R / (4\pi d^2) \quad ...(2.3)$$

The product $P_T G_T$ is called effective isotropic radiated power (EIRP) ... G_R ...

$$G_R = \frac{4\pi A_R}{\lambda^2} \quad ...(2.4)$$

Substituting Eq. (2.4) into Eq. (2.3) one gets

$$P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2 \quad ...(2.5)$$

The power attenuation expressed in decibels is

$$\alpha_{dB} = 10 \operatorname{Log}_{10} \frac{P_T}{P_R}. \text{ Thus}$$

$$\alpha_{dB} = 22 + 20 \operatorname{Log}_{10}\left(\frac{d}{\lambda}\right) - G_T - G_R \quad ...(2.6)$$

$$L_{FS} = 22 + 20 \operatorname{Log}_{10} (d/\lambda) \text{ dB} \quad ...(2.7)$$

This free space loss L_{FS} is expressed in dB and actually expresses the signal power attenuation between two isotropic antennas in free space. Eq.(2.7) indicates that this free space loss varies with frequency, the higher the frequency, the higher the free loss. However, this increased loss is compensated by the increase in the antenna gain with increased frequency, for a given antenna aperture area. Thus the path Loss between a satellite in geostationary orbit and the earth station (sub satellite point) is 195.6 dB and 199.1 dB at 4 GHz and 6 GHz respectively.

Now, $L = \left(\frac{4\pi d}{\lambda}\right)^2 \cdot L_A$

$$\boxed{\frac{P_R}{P_T} = \frac{G_T G_R}{L}} \qquad ...(2.8)$$

$L_{FS} = \left(\frac{4\pi d}{\lambda}\right)^2$

L_{FS} (dB) =

Here the additional losses L_A be written as[4]

$$L_A = L_{FTX} * A_{AG} * A_{Rain} * L_{POL} * L_{Point} * L_{FRX} \qquad ...(2.9)$$

where

L_{FTX} represents losses between the transmitter output and the transmitting antenna (wiring, duplexers, filters etc),
A_{AG} represents attenuation by the atmosphere and ionosphere,
A_{Rain} represents attenuation due to precipitations and clouds,
L_{POL} represents losses caused by polarization mismatch between the transmitting and receiving antenna
L_{point} represents losses caused by a antenna depointing,
L_{FRX} represents losses between the receiving antenna and the receiver input (wiring, duplexer etc).

Thus Eq.(2.8) can be written as

$$P_R = EIRP + G_R - L_{FS} - L_{FTX} - A_{AG} - A_{Rain} - L_{POL} - L_{Point} - L_{FRX} \qquad ...(2.10)$$

It may be noted that the gain of an antenna is expressed in terms of the actual surface area A by the equation

$$G = \frac{4\pi\eta A}{\lambda^2} \qquad ...(2.11)$$

2.3. System Noise Temperature, C/N and G/T Ratio

The *noise temperature* is an important parameter that governs the performance of receiver and therefore the design of satellite links. Infact the most important source of noise in the receiver is the thermal noise in its preamplifier. The noise power P_N in the receiver is given by

$$P_N = KTB \qquad ...(2.12)$$

where T is the receiver noise temperature, B is the bandwidth and K is the Boltzman constant. Actually P_N is the available noise power and is delivered only to a device that is impedance matched to the source. The system noise temperature T_s is also called the effective input noise temperature of the receiver and is defined as the noise temperature of a noise source located at the input of a noiseless receiver which would produce the same contribution to the receive output noise as the internal noise of the actual system itself. The equivalent noise source T_s is usually located at the input to the receiver replacing the antenna. The receiver has a rf amplifier and IF amplifier prior [illegible] gain of the receiver is G (G is [illegible] is B, the noise power at the [illegible]

$$\boxed{P_n = KT_s BG} \qquad ...(2.13)$$

If P_r is the signal power at the input to the RF section of the receiver, the signal power at the demodulator input would be $P_r G$. Hence the carrier to noise ratio (C/N) at the demodulator input is given by

$$\frac{C}{N} = \frac{P_r G}{KT_s BG} = \frac{P_r}{KT_s B} \qquad ...(2.14)$$

[illegible]

as T_{rf}, T_m and T_{if}. Similarly let their respective gains be G_r, G_m and G_{if}. If T_{in} is input noise temperature at the RF section then the total noise power at the output of the IF amplifier would be given by

$$P_n = G_{if} K T_{if} B + G_{if} G_m K T_m B + G_{if} G_m G_{RF} KB\,(T_{RF} + T_{in}) \qquad ...(2.15)$$

T_n is actually the noise temperature of the antenna measured at the receiver input. Rewriting Eq.(2.15) in the following form as

$$P_n = G_{if} G_m G_{Rf} \left[\frac{KT_{if}B}{G_m G_{if}} + \frac{KT_m B}{G_{RF}} + kB\,\{T_{Rf} + T_{in}\} \right]$$

$$= G_{if} G_m G_{Rf} KB \left[T_{Rf} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{if}}{G_m G_{Rf}} \right] \qquad ...(2.16)$$

In terms of T_s, the same noise power P_n at the output of IF amplifier would be given by

$$P_n = G_{if} G_m G_{Rf} K T_s B \qquad ...(2.17)$$

From Eqs.(2.16) and (2.17) one gets

$$KT_s B = KB \left[T_{Rf} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{if}}{G_m G_{Rf}} \right]$$

or

$$T_s = \left[T_{Rf} + T_{in} + \frac{T_m}{G_{RF}} + \frac{T_{if}}{G_m G_{Rf}} \right] \qquad ...(2.18)$$

It would be of importance to note that beyond IF stages, the noise contributed by other units are negligible. From Eqs.(2.5) and (2.8), Eq. (2.14) can be rewritten as

$$\frac{C}{N}=\frac{P_T G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2}{K T_s B L_A} \qquad \ldots(2.19)$$

If $N_0 = N/B$ which is also called the noise power spectral density (W/Hz) the carrier power to noise power spectral density ratio is given by

$$\left(\frac{C}{N_0}\right)_{dBHz} = \underbrace{10\mathrm{Log}\,P_T G_T}_{EIRP(dBW)} - \underbrace{20\mathrm{Log}\frac{4\pi d}{\lambda}}_{\text{free Space Loss}(dB)}$$

$$+\,10\mathrm{Log}\frac{G_R}{T_s} - \underbrace{10\mathrm{Log}\,L_A}_{\text{Additional Loss}} - 10\mathrm{Log}\,K \qquad \ldots(2.20)$$

In abo...

... ratio and is the *figure of merit*. For standard *A* earth station (*e.g.* used in Intelsat network) *G/T* ratio is 40.7 db K^{-1} at 4.0 GHZ and 5° elevation angle. It should be noted that while describing the *G/T* ratio especially at 4 GHz, it is essential to specify the frequency and elevation angle because G_r varies as f^2 across the frequency band and T_s depends on sky noise temperature, which increases as the elevation angle is ...

... value of G_r is smaller than the numerical value of T_s.

It would be of importance to ... system noise temp... or satellite power ...

... approximately 15 K each.

2.4. Atmospheric and Ionospheric Effects on Link Design

The free space loss and other ... ionospheric) enc... medium are ex... explained in Section 2.1 while deciding the frequencies for upper link and lower links. In this section the atmospheric and ionospheric attenuation will

be discussed in some details. It is widely known that the atmospheric and ionospheric propagation are subject to absorption, diffusion (or diffraction) refraction, rotation of the polarization plane of the electromagnetic wave. These effects are dependent on the path length and so are more pronounced at small elevation angles. The lower layers of atmosphere cause absorption and diffusion. These cause some kind of emission and so an increase in the noise power at the receiving antenna is created. The upper layer of the atmosphere (the troposphere) causes refraction and the depolarization is produced when the radio waves traverse the ionosphere.

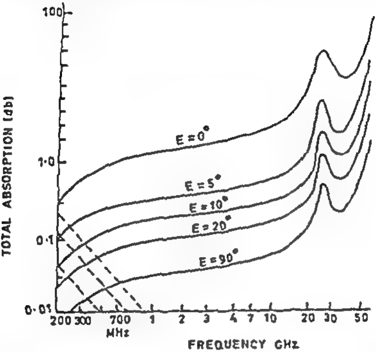

Fig.2.2. Total Atmospheric Attenuation as a Function of Frequency for Different Elevation Angles E. Solid Lines (——) Represent Tropospheric Attenuation and Dash Lines (---) Represent Ionospheric Attenuation.

Atmospheric attenuation is of no importance at frequencies below 10 GHz but as mentioned in Section 2.1 there are a few molecular resonance absorption lines at which the signal attenuation is extreme. Oxygen and water vapour have such absorption bands but these are of no significance at 6/4 GHz. Fig. 2.2 [illegible]

The rain attenuation depends on frequency, rainfall rate, diameter and tribution of raindrops. It is estimated by the formula.

$$\boxed{A_{mm} = \gamma_r L_e} \qquad ...(2.21)$$

where γ_r is the specific rain attenuation in db/km and L_e is the effective path length. Various reports of CCIR are available regarding rainfall rate and

ionospheric scintillation etc are quite small for frequencies below 30 GHz.

2.5. Uplink Design

The design of uplink is easier as in this case firstly the noise at the satellite is of no concern and high power transmitter can be designed at earth station so as to put accurately specified carrier power density at the satellite transponder input. Calculations for uplink design may be easily carried out by using

$$\left(\frac{C}{N_0}\right)_{uplink\ in\ dbHz} = 10\,\mathrm{Log}\,P_T G_T - 20\,\mathrm{Log}\frac{4\pi d}{\lambda} + 10\,\mathrm{Log}\frac{G}{T}$$

$$- 10\,\mathrm{Log}\,L_A - 10\,\mathrm{Log}\,K - BO_i \qquad ...(2.22)$$

where BO_i is the input back off in db[7]. This backoff is of the order of 3 to 7 dB.

2.6. Complete Link Design

A single complete link consists of two earth stations and a satellite. Here radio relay is done by the satellite. Thus the complete link is made up of *uplink* and *downlink*. Therefore the ultimate information quality received on earth depends on the uplink, the satellite transponder and the downlink. The uplink is characterized by the carrier power (signal power) to noise power spectral density ratio $(C/N_0)_U$ at the transponder input. The downlink is similarly

the receiving earth station receiver input is given as

$$C = \frac{C_u G_B G_T G_R}{L} \qquad ...(2.23)$$

where C_u is the signal power at the satellite transponder input (uplink power), G_S, G_T and G_R are the satellite transponder gain, the satellite transmitting [illegible]

$$N_0 = N_{0D} + N_{0u}\,(G_s G_T G_R)/L \qquad \ldots(2.24)$$

where N_{0u} is the noise power density at the transponder input and N_{0D} is the noise power density at the input to receiving earth station receiver. Thus

$$\left(\frac{C}{N_0}\right)_T = \frac{C}{N_0} = \frac{C_u G_s G_T G_R / L}{N_{0D} + N_{0u}\,(G_s G_T G_R)/L}$$

$$= \frac{C_u}{N_{0u} + \frac{N_{0D} \cdot L}{G_s G_T G_R}} \qquad \ldots(2.25)$$

Now, if the transponder has bandwidth B and radiates a constant power P_T, its gain G_s would be expressed by

$$G_s = \frac{P_T}{C_u + n_{0u} * B} \qquad \ldots(2.26)$$

For downlink only the signal power C_D is

$$C_D = \frac{P_T G_T G_R}{L} \qquad \ldots(2.27)$$

Thus

$$\frac{C}{N_0} = \frac{C_u}{N_{0u} + \frac{N_{0D} \cdot L\,(C_u + N_{0u} * B)}{P_T \cdot G_T G_R}}$$

or

$$\frac{C}{N_0} = \frac{C_u}{N_{0u} + \frac{N_{0D} \cdot (C_u + N_{0u} * B)}{C_D}}$$

$$= \frac{(C/N_0)_u \cdot (C/N_0)_D}{(C/N_0)_D + (C/N_0)_u + B} \qquad \ldots(2.28)$$

In most of the cases B is much smaller than $(C/N_0)_D$ and $(C/N_0)_u$. So neglecting B, Eq. (2.28) gives

$$(C/N_0)_T^{-1} = (C/N_0)_u^{-1} + (C/N_0)_D^{-1} \qquad \ldots(2.29)$$

Normally $(C/N_0)_u$ is much greater than $(C/N_0)_D$. Though N_{0D} is much higher (around 10 times) than N_{0u} but C_u is around 100 times higher than C_D and therefore $(C/N_0)_u$ is 10 times $(C/N_0)_D$. In such a case

$$(C/N_0)_T \cong (C/N_0)_D \qquad \ldots(2.30)$$

Thus the overall (complete) link design depends on the quality of downlink and especially on $(C/N_0)_D$. Since with a geostationary satellite the value of $(C/N_0)_D$ depends only on EIRP of the satellite plus the figure of merit of the earth station, Eq. (2.30) indicates that in the complete design link the capabilities of satellite transmitter and earth station receiver are dominant factors.

Eq.(2.30) [illegible] be extended to include the effects of interfering signals [illegible] uplink)

$$(C/N)_{\text{Net uplink}} = [(C/N)_u^{-1} + (C/I)_u^{-1}]^{-1} \qquad ...(2.31)$$

where $(C/N)_u$ is the carrier to noise ratio for uplink in the absence of interference signals and $(C/I)_u$ is the carrier to noise ratio of the interference signals for uplink. A similar expression for downlink net carrier to noise ratio is given by

$$(C/N)_{\text{Net downlink}} = [(C/N)_D^{-1} + (C/I)_D^{-1}]^{-1} \qquad ...(2.32)$$

Thus from Eq.(2.29) the net carrier to noise ratio is given by

$$(C/N)_{\text{Net}} = [(C/N)_{\text{Net uplink}}^{-1} + (C/N)_{\text{Net downlink}}^{-1}]^{-1}$$

$$= [(C/N)_u^{-1} + (C/I)_u^{-1} + (C/N)_D^{-1} + (C/I)_D^{-1}]^{-1}$$

$$= [(C/N)^{-1} + (C/I)^{-1}]^{-1} \qquad ...(2.33)$$

where $\qquad (C/I)^{-1} = (C/I)_u^{-1} + (C/I)_D^{-1} \qquad ...(2.34)$

Here C/N represents the carrier to noise ratio of overall link and C/I, the carrier to interference ratio of the overall link. In case $C/I > C/N$ for such a [illegible]

[illegible] satellite link between two earth stations may be designed to achieve a specified [illegible]

demodulator the output S/N after the demodulator is given by

$$(S/N)_{out} = (C/N)_{in} + FM \text{ improvement}. \qquad ...(2.35)$$

[illegible]

particularly with the analog signals. In terms of power ratios rather than db, Eq.(2.35) can be written as

$$\frac{S}{N_{out}} = \frac{C * FM \text{ improvement}}{N_{in}} \qquad ...(2.36)$$

2.7. Interference Effects On Complete Link Design

mentioned previously the 6/4 GHz frequency bands allocated to the satellite communications are also allocated to the terrestrial microwave links. Thus the receiving earth station working at 4 GHz band is susceptible to interference

cross

circular polarizations (left-hand and right-hand circular polarization) are being used for transmission purposes. In such cases there may exist a

antennas that determines the cross-polarization interference.

polarization discrimination of earth station and satellite antennas respectively the minimum net link cross polarization discrimination is given by

$$X_{min} = \frac{1}{2}\left(X_1^{-1} + X_2^{-1}\right)^{-1} \qquad \ldots(2.37)$$

X_{min} is actually the worst case carrier to cross polarization interference ratio $(C/I)_x$ and can be used in Eqs. (2.33) and (2.34) as an additional interference source to obtain the total carrier-to-noise ratio plus the interference ratio.

... satellite link is

or near saturation point the TWTA may also create *inter symbol interference* which also degrades the link performance. In linear channels the intersymbol interference may be removed by using the *Nyquist pulse shaping criterion*

2.8. Earth Station Parameters

From Eq. (2.19), the C/N ratio is given by

$$\frac{C}{N_0} = \frac{P_T G_T G_R}{N_0}\left(\frac{\lambda}{4\pi d}\right)^2 \frac{1}{L_A} \qquad \ldots(2.38)$$

Here d is the range between transmitting and receiving antennas. The antenna parameters such as its diameter D and antenna beam width θ_{3dB} affect the C/N_0 as these are linked to the gain by the expressions given by

$$G = \eta\left(\frac{4\pi D}{\lambda}\right)^2 \qquad \ldots(2.39)$$

and

$$G = \frac{\eta\, 4\pi^2 70^2}{\theta_{3dB}^2} \qquad \ldots(2.40)$$

where η is the antenna efficiency. The satellite antenna beamwidth $(\theta_{3dB})_{sat}$ is determined by the required earth coverage. For a given earth station antenna diameter D_{ES}, Eq.(2.38) gives C/N_0 as

$$\frac{C}{N_0} = \frac{P_T}{L_A N_0}\eta_T \eta_R \times \frac{\pi^2 70^2}{d^2}\frac{D_{Es}^2}{(\theta_{3dB})_{sat}^2} \qquad \ldots(2.41)$$

where η_T and η_R are the efficiencies of transmitting and receiving antennas respectively. It is evident from Eq.(2.41) that frequency does not come into the C/N_0. However, if the earth station antenna beamwidth (θ_{3dB}) is fixed, then C/N_0 is given by

$$\frac{C}{N_0} = \frac{P_T}{L_A N_0}\eta_T \eta_R \frac{\pi^2 C^2 70^4}{(4d)^2 (\theta_{3dB})^2_{sat} (\theta_{3dB})^2_{Es} \cdot f^2} \qquad \ldots(2.42)$$

expression for C/N_0 reduces to

$$\frac{C}{N_0}=\frac{P_T}{L_A N_0}\eta_T\eta_R\left(\frac{\pi D_{sat}D_{Es}}{4dC}\right)^2 f^2 \qquad \ldots(2.43)$$

In such cases C/N_0 increases with frequency. It may be recalled that it is the G/T ratio that characterizes the earth stations. This is due to the fact that

is achieved. Thus an optimum, value of G/T ratio is to be achieved by having

it has been found that increasing the antenna aperature area is more cost effective than to lower the system noise temperature.

2.9. Review Questions

1. What are the factors that affect the uplink design and the downlink design in geostationary satellite communication ? Discuss in detail.
2. [illegible]
3. [illegible] ratios ?
4. [illegible] db, find the received power.

   [Ans. Flux density = 4.97×10^{-15} W . m^2, Power received = - 133 dbW for both the cases].
5. [illegible] working on 4 GHz, the typical various [illegible] = 50 K, T_{sp} = 50 K, T_m = 500 K, T_{IF} = [illegible] = 30 dB. Calculate the system noise temperature.

   [Ans. T_s = 107.5 K]
6. For an earth station having an antenna of diameter 30m and overall efficiency of 68%, the working signal frequency is 4150MHz. At this frequency the system noise temperature is 79 K when the antenna points at the satellite at an elevation angle of 28° K. Calculate *G/T ratio of the earth station. In case* the sky noise temperature rises to 88 K, what would be the new *G/T* ratio ?

   [Ans. 41 6.dB K^{-1}, 41.2 dB K^{-1}]

7. [illegible] earth stations have 2 m diameter antennas, and the receiver noise temperature is 125 K. The same antenna is used for both transmission and reception. Calculate the power transmitted by the satellite and the earth station, knowing that the uplink is at 6 GHz and the down link at 4.6 GHz.
8. How is the uplink design different than the downlink design ? In what conditions a complete satellite link become down link limited ?
9. What are the various interferences that may affect the satellite link performance ? Explain as to how these interference effects are taken into account in the satellite link design ?
10. Explain the parameters that control the design of earth station. What is the optimum G/T ratio for a standard A earth station ?

2.10. References

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THREE

Satellite Analog Communication

3.1 Introduction

During 1960's analog communication was predominant in terrestrial communication systems and therefore such analog voice and video transmission systems were also adopted in commercial communication

In the modern communication satellites, however, digital modulation

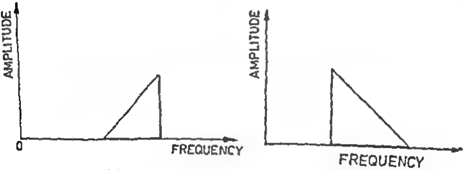
mentioned in Section 1.8. It may be noted that in several satellite communication systems like those of INTELSAT huge investment has already been made for fdm/fm telephone systems and are still widely used. And therefore in this chapter the satellite analog communication techniques are discussed.

3.2. Baseband Analog (Voice) Signal

The baseband signal may be analog or digital. The analog baseband signal is the voice signal (in the form of voltage) generated by a telephone set. The digital baseband signal is the output from a computer terminal or so. The digital baseband signal would be discussed in next chapter. Normally the characteristics of a baseband voice signal would depend on the speaker but the Bell system treats it as having a flat spectrum extending from 300 to 3100

GHz. CCITT has recommended 3000 to 3400 Hz for it and this is being followed now internationally, *e.g.* Intelsat system follows the same. The spectrum of such a baseband voice signal is represented in the form of a triangle [illegible]

As usual the amplitude of baseband voice signal of telephone output is expressed in terms of signal powers *i.e.* in terms of *transmission level* with respect to a reference point. The signal power at the reference point is indicated by the unit dbmo where o represents zero transmission level point or the test point. Thus a - 2 dbmo signal means a signal producing an average power of -2 dbm at the reference point. The CCIR assumes that the long term average power carried by a single voice channel in a telephone system is taken to be -15 dbmo. However, in most of the cases, it is taken as -18 dbmo. The peak instantaneous power in the channel is about 18 db higher or o dbmo. Thus [illegible] terrestrial FDM/FM links and -22 dbmo for some satellite links.



(*a*) (*b*)

Fig 3.1 Spectrum of Baseband Voice Signal from a Telephone Set (*a*) Normal Spectrum, (*b*) Inverted Spectrum

3.3. Frequency Division Multiplexing Techniques

As previously mentioned in satellite communication (along) frequency modulation is being used. From economic point of view several users can share a satellite and so the satellite link will normally relay many signals from a [illegible] communications it is *time division multiplexing (tdm)*. Here we shall discuss only fdm. In a simplified approach, the fdm allows transmission of signals on different frequencies whereas in the tdm the signals enter the transponder at different times. The fdm scheme for the satellite communications is shown in Fig. 3.2. Actually each satellite has a certain number of transponders which

work as receiver-transmitter pair. The satellite receiver is a wide-band receiver and it covers the entire range of uplink frequencies. Though the uplink frequency is said to be around 6 GHz, it has a bandwidth of 500 MHz to accommodate various channels. In Fig 3.2 (*a*) this uplink frequency range is from 5.925 to 6.425 GHz (a bandwidth of 500 MHz) that incorporates 12 channels. The wideband receiver of the satellite will receive these all 12 different channels. In order that these 12 different channels may not interfere with each other, each channel is assigned a bandwidth of 36 MHz with a 4 MHz spacing between channels. Above 12th channel there is a 20 MHz command and control of telemetry channel. After having these different frequencies received by the satellite wide band receiver, the transponder converts the uplink frequency ranges in the form as shown in Fig 3.2 (*b*). This range of downlink frequencies varies between 3.72 to 4.20 GHz.

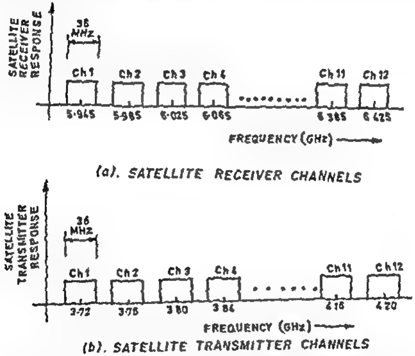


Fig 3.2. Frequency Division Multiplexing in a Communication Satellite

3.4. Signal to Noise (S/N) Ratio and (C/N) Ratio in Frequency Modulation in Satellite Link

Frequency modulation has poor spectral efficiency but it offers wider bandwidth and considerable S/N (signal to noise ratio) improvement. This S/N

A frequency modulated signal is expressed by

$$E(t) = A\cos(\omega_c t + m\sin\omega_m t) \qquad \ldots(3.1)$$

where ω_c is the carrier frequency, ω_m is the modulating signal and m is the *FM* modulation index given by

$$m = \frac{\Delta\omega}{\omega_m} \qquad \ldots(3.2)$$

where $\Delta\omega$ is the frequency deviation. It is related to the instantaneous amplitude of the modulating signal (A_m) by the expression

$$\Delta f = KA_m \qquad \ldots(3.3)$$

where K is constant.

Thus frequency modulation results when the deviation Δf of the instantaneous frequency f from the carrier f_c is directly proportional to the instantaneous amplitude of the modulating voltage. The frequency spectrum of the fm modulated signal consists of an infinite series of discrete components and may be expressed as

$$E(t) = A\,\{J_0(m)\cos\omega_c t + \sum_{n=1} J_n(m)\,[\cos(\omega_c + n\omega_m)\,t$$

$$+ (-1)^n \cos(\omega_c - n\omega_m)\,t]\} \qquad \ldots(3.4)$$

where the $J_0, J_1, \ldots, J_n$ are Bessel functions of the first kind and order 0, 1, 2, .. n. From Eq (3.4) it is evident that the fm signal has infinite number of side frequencies and so has infinite bandwidth. However, for most of the transmission purposes a finite bandwidth is needed and so some of the side frequencies need to be filtered out by means of a band limiting filter. This finite bandwidth of fm signal is represented by Carson's rule

$$B = 2f_m(m+1)$$

$$= 2(\Delta f + f_m) \qquad \ldots(3.5)$$

Here Δf is the peak frequency deviation of the system, and f_m is the modulating frequency. It may be noted that the spectrum of an fm waveform modulated by a real signal is much more complicated than that for a single-frequency sinusoid. In such a case f_m is replaced by f_{max}, the maximum modulating frequency and then

$$B = 2(\Delta f + f_{max}) \qquad \ldots(3.6)$$

The energy associated with the sidebands outside the bandwidth B is very small and so when the fm, signal is passed through a filter of bandwidth B, very little distortion occurs in the [illegible]

[illegible]

compression has been achieved by the fm detector. There is an improvement in the signal-to-noise ratio $(S/N)_0$ associated with this bandwidth compression.

Actually the performance of a conventional FM receiver in the presence of random fluctuation noise is commonly judged on the basis of the variation of [illegible] detector is given by[14]

$$(S/N)_o = (C/N)_i * \frac{3}{2} m^2 \qquad ...(3.7)$$

$$(S/N)_{odb} = (C/N)_{idb} + 10 \log \frac{3}{2} m^2 \qquad ...(3.8)$$

The factor $10 \log (3/2) m^2$ expresses in decibels precisely the improvement afforded by the fm system in return for a sacrifice for bandwidth. The [illegible] discussed in the next section. With a phase detector, Eq (3.7) of signal - to - noise improvement ratio is given by

$$(S/N)_o / (C/N)_i = (\Delta\phi)^2 \qquad ...(3.9)$$

where $\Delta\phi$ = peak phase deviation. The above discussion about the $(S/N)_o$ improvement was limited to the case of a single frequency sinusoidally [illegible] FM signal. For the case of a non sinusoidal modulating signal e.g. [illegible]

$$(S/N)_o = (C/N)_i \cdot \frac{3}{2} \frac{B}{f_{max}} \left(\frac{\Delta f_{peak}}{f_{max}} \right)^2 \qquad ...(3.10)$$

where B is the bandwidth expressed in terms of Carson's rule as

$$B = 2 f_{max} (1 + m) \qquad ...(3.11)$$

Here f_{Max} is the highest modulating frequency and Δf_{peak} is the peak frequency deviation. Since

$$m = \Delta f_{peak} / f_{max} \qquad ...(3.12)$$

Eq (3.10) gives

$$(S/N)_o = (C/N)_i * 3 (1 + m) m^2 \qquad ...(3.13)$$

For large m, $3(1+m)\,m^2 \approx 3m^3$

Similarly, for $m \ll 1$, $3(1+m)\,m^2 \approx 3m^2$

Thus Eq.(3.13) shows that better $(S/N)_0$ can be improved by increasing the carrier power (or in other words) by increasing the level of modulating baseband signal) to the maximum extent possible until the distortion exceeds a specified value. The distortion occurs because eventually the frequency deviation exceeds the specified IF bandwidth. In an audio baseband signal the power spectral density is relatively high in the low frequency range and falls

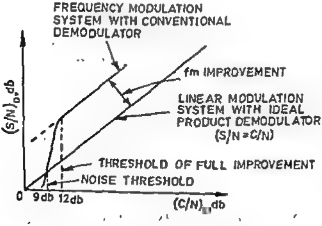


Fig 3.3. Threshold in FM Detector

3.5. S/N Ratio in Frequency Modulation with Multiplexed Telephone Signals in Satellite Link : (Noise Performance in Telephone Channel)

$$(S/N)_{wc} = (C/N)_t * (B/b)\left(\frac{\Delta f_{rms}}{f_{max}}\right)^2 \qquad ...(3.14)$$

where the subscript wc represents worst channel, b is the *voice channel* bandwidth (usually 3100 Hz), B is the rf bandwidth, Δf_{rms} is the rms frequency deviation and $(C/N)_t$ is the overall carrier to noise ratio of the link. Since the [illegible] of the telephone receiver and of the user's ear. The Bell System calls this weighting factor as C-message weighting. The CCITT calls it *psophometric weighting factor* [9] whose numerical value is 1.78 (2.5 db). It would be worthwhile to mention that 'psophometrically weighted power' means that [illegible] improvement factor q is to be included in S/N ratio. Thus, taking into account both the psophometric weighting factor p and pre-emphasis improvement factor q, the expression (3.14) of $(S/N)_{wc}$ becomes

$$(S/N)_{wc} = (C/N)_t (B/b)\left(\frac{\Delta f_{rms}}{f_{max}}\right)^2 pq \qquad ...(3.15)$$

which may be rewritten in the decibel form as

$$(S/N)_{wc} = (C/N)_t + 10\,\mathrm{Log}_{10}(B/b) + 20\,\mathrm{Log}_{10}\left(\frac{\Delta f_{rms}}{f_{max}}\right) + p + q\ db \qquad ...(3.16)$$

where p is 2.5 db and q is 4 db. The above quantities Δf_{rms} and B are also used to calculate the number of channels N carried by a multiplex telephone signal and to the available transponder bandwidth. For such a calculation the concept of *rms test-tone deviation* (also abbreviated at Δf_{rms}) is used. Actually this is a rms carrier deviation that a single 1 -kHz-O dbm sine wave called the test [illegible]

$$20\log(l) = -1 + 4\log_{10}(N),\ 12 \le N \le 240$$
$$= -15 + 10\log_{10}(N),\ N > 240 \qquad ...(3.17)$$

The product $l\,\Delta f_{rms}$ is termed the *rms multicarrier deviation.* Another factor g is defined as the ratio of the peak frequency deviation Δf_p to the rms multicarrier deviation $l\,\Delta f_{rms}$, *i.e.*

$$g = \frac{\Delta f_p}{l\Delta f_{rms}} \qquad ...(3.18)$$

...orresponding to 10 db) and for small ... ue of 6.5 (18.8 db). Now the Carson's

$$B = 2\,(\Delta f_p + f_{max}) \qquad ...(3.19)$$

where Δf_p is peak frequency deviation and f_{max} is the maximum frequency component of the baseband modulating signal. Eq.(3.19) combined with Eq.(3.18) gives

$$B = 2\,(g\,l\Delta f_{rms} + f_{max}) \qquad ...(3.20)$$

which gives the expression for Δf_{rms}, the rms test deviation as

$$\Delta f_{rms} = \left(\frac{B}{2} - f_{max}\right) / \, g\,l \qquad ...(3.21)$$

The value of B being fixed for a given transponder design, the number of voice channels per transponder is computed by an iterative procedure. Starting with an estimate for N, computed values of f_{max} and Δf_{rms} are introduced in Eq (3.16) together with the rf channel C/N power ratio. If the resulting S/N turns out to be greater (or smaller) than the prescribed S/N (normally 51.25 db), the estimate for N was too low (or too high) and needs to be changed until the correct value of S/N is found. It would be worthwhile ...

... for the earth station out-of-band noise, the balance of 7500 pwp is the noise allowed for the combination of the up and down links. Hence

$$\frac{S}{N} = 10^{-3} / (7500 \times 10^{-12}) = 1.33 \times 10^{5}$$

or

$$\frac{S}{N}\,\text{dB} = 51.25\text{dB} \qquad ...(3.22)$$

3.6. Single Channel Per Carrier (SCPC) Systems

The fm-fdm is used with large earth stations which serve large capacity links. The single channel per carrier system or (SCPC technique) is suitable for small earth stations with relatively few channels. Here each channel independently modulates its own carrier and is transmitted to transponder. Earth stations using SCPC systems thus do not need the expensive

and demultiplexing equipment and so the cost of such earth stations is considerably reduced. Further in such earth stations the carrier would be transmitted only when the link is active or needed. In large earth stations the carrier is always present as there are permanently assigned channels for the various other stations. This causes a continuous consumption of satellite [illegible] a given time. To accomplish this sharing requires a central control station, or equivalent means, to do the assigning on demand using manual, semiautomatic, or fully automatic methods. Also, each station must have equipment to permit a given voice channel to be switched to any of the assignable frequencies for both transmission and reception. It would be worthwhile to mention here that SCPC requires more bandwidth than FM/FDM for the same number of channels and so it is not an economical way to move large amounts of traffic over a fixed route between two earth terminals.

The signal to noise (S/N) behaviour of an SCPC link is described by Eq.(3.13) alongwith the modification for appropriate preemphasis and weigthing. Using 6.3 db for preemphasis improvement and 2.5 db for psophometric noise weighting, the $(S/N)_0$ for an analog FMSCPC system is given as

$$(S/N)_0 = (C/N_0)_t - 95.4 + 20\text{Log}_{10}(\Delta f_p)dB \qquad \ldots(3.23)$$

where N_0 is the noise power density in Watts per hertz and Δf_p is the peak test tone deviation in hertz. It should be noted that (C/N_0) is related to (C/N) by the expression given by

$$(C/N) = (C/N_0) - 10\text{Log}_{10}(B)\,dB$$

where B is the bandwidth given by Eq (3.19). By using a technique called *companding* where the dynamic range of speech is compressed before transmission and is expanded after detection, an improvement in S/N is obtained. Actually companding distorts a voice waveform in a way that [illegible] given as

$$(S/N)_0 = (C/N_0)_t - 78.4 + 20\text{Log }10\,(\Delta f_p) \qquad \ldots(3.24)$$

A typical improvement of the order of 16 dB in S/N ratio has been obtained by such companding technique in SATCOM systems.

3.7. Companded Single Sideband (CSSB) Systems

[illegible]

low-level speech signals. During pauses in the speech signal, channel noise is further reduced by expander. Thus whereas an uncompanded FM/FDM 36 MHz could accommodate 1100 voice channels, the companding increases the

In the single side band suppressed carrier system the individual voice channels are 'stacked' in frequency and then added to form a multiplexed

for 36 MHz, 9000 channels could be accommodated but due to certain practical considerations, only 6000 channels are allowed. Companding to this will provide improvement in overall *S/N* ratio.

3.8. Analog FM/FDM TV Satellite Link

depend on the transponder bandwidth available. Typical values for network TV are a peak deviation Δf_p of 10.75 MHz and a maximum video modulating frequency f_v of 4.2 MHz. The performance of fm-fdm television channel is expressed in terms of the peak to peak luminance signal-to-noise ratio. For a sinusoidal wave, the peak-to-peak power is $(2\sqrt{2})^2$ times the rms power. Also, the peak-to-peak value of the luminance signal is $1/\sqrt{2}$ times the peak-to-peak value of the composite television channel. Thus, from Eq (3.10) and taking into account the preemphasis factor and weighting factor as discussed in Eq.(3.15), the peak-to-peak luminance signal-to-noise ratio for a fm-fdm TV signal is

$$(S/N)_{pp} = (2\sqrt{2})^2\left(\frac{1}{\sqrt{2}}\right)^2 \cdot (C/N)_t \cdot \frac{3}{2}\frac{B}{f_{max}}\left(\frac{\Delta f_{peak}}{f_{max}}\right)^2 pq$$

$$= 6\left(\frac{C}{N}\right)_t \left(\frac{B}{f_{max}}\right)\left(\frac{\Delta f_{peak}}{f_{max}}\right)^2 pq \qquad \ldots(3.25)$$

where p is the preemphasis factor, q is the weighting factor, f_{max} is the maximum video modulating frequency (4.2 MHz by US standards) and the modulation index m is the ratio of $\Delta f_{peak}/f_{max}$. Eq.(3.25) can also be written in the form similar to Eq.(3.13) as

$$(S/N)_{pp} = 6\,(C/N)_t \cdot 3\,(1+m)_m^2\, pq \qquad \ldots(3.26)$$

direct broadcast satellites (DBS) these parameters are B = 24 MHz, $f_m = 4.2$ MHz, Δf_p $B/2 - f_{max} = 7.8$ MHz and $pq = 12.8$ db. Then $(S/N)_{pp}$ reduces to

$$(S/N)_{pp} = 40.24 + (C/N)_i \,(\text{dB}) \rightarrow (FSS) \qquad ...(3.27)$$

$$(S/N)_{pp} = 33.53 + (C/N)_i \,(\text{dB}) \rightarrow (DBS) \qquad ...(3.28)$$

Thus, for a clear sky *C/N* ratio of 14 db, the receiver (*S/N*) ratio for a DBS TV channel is 47.5 dB.

3.9. Intermodulation Products and their Effects in FM/FDM Systems

It has been already mentioned that TWTA while operating at its saturation [illegible]

introduced in the TWTA amplifier design so that TWTA may not work near its saturation region and this will reduce the intermodulation effects. The multicarrier amplitude transfer characteristics of TWTA is represented by an odd polynomial such as [4]

$$V_0 = a_1 V_i + a_3 V_i^3 + a_5 V_i^5 + \ldots.. \qquad ...(3.29)$$

where V_o = output voltage of TWTA
V_i = input voltage
a_i = constants having positive and negative values alternatively. Then carrier input signal is considered to be of equal amplitude and may be expressed as

$$V_i = \sum_{i=1}^{n} A \cos(\omega_i t + \theta_i(t)) \qquad ...(3.30)$$

Therefore the total input power P_{ii} is

$$P_{ii} = \frac{nA^2}{2} \qquad ...(3.31)$$

or

$$A = \sqrt{\frac{2P_{ii}}{n}} \qquad ...(3.32)$$

On substituting Eq.(3.30) *for* V_i into Eq.(3.29) one gets

$$V_0 = \sum_{i=1}^{n} B_n \cos[\omega_i t + \phi_i(t)] + IM + H \qquad ...(3.33)$$

where H represents harmonics kw_i that can be filtered out. IM represents intermodulation products which fall into the bandwidth of the carriers. These intermodulation products are located at frequencies $2\omega_i - \omega_{i+1}$, $\omega_i + \omega_{i+1} - \omega_{i+2}$, and so on. These fall within the transponder bandwidth and interfere with each other. Westcott[5] has calculated the amplitude B_n of the individual output carrier and the expression is given as

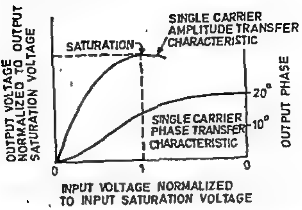


Fig 3.4. Operational Characteristics of TWTA Near At Its Saturation Point

$$B_n = a_1\sqrt{\frac{2P_{il}}{n}}\{1+\frac{3a_3}{a_1}\left(\frac{P_{il}}{n}\right)\left(n-\frac{1}{2}\right)$$

$$+15\frac{a_5}{a_1}\left(\frac{P_{il}}{n}\right)^2\left[\frac{1}{6}+(n-1)(n-2)+\frac{3}{2}(n-1)\right]$$

$$+105\frac{a_7}{a_1}\left(\frac{P_{il}}{n}\right)^3[(n-1)(n-2)(n-3)$$

$$+3(n-1)(n-2)+\frac{34}{24}(n-1)+\frac{1}{24}]+\ldots\ldots\} \quad \ldots(3.34)$$

Here the term $a_1\sqrt{\frac{2P_{il}}{n}}$ gives the output amplitude due to the first term of the amplitude transfer characteristic and the term inside the brackets is the amplitude compression factor due to amplitude non-linearity. It should be noted that the third order type of intermodulation products located at frequency $2\omega_i-\omega_{i+1}$ and $\omega_i+\omega_{i+1}-\omega_{i+2}$ are the most dominant. Among others the fifth order types at frequency $3\omega_i-2\omega_{i+1}$ is less important. Westcott [5] has also calculated the amplitudes V_{21}, V_{111} and V_{32} of the intermodulation products $2\omega_i-\omega_{i+1}$, $\omega_i+\omega_{i+1}-\omega_{i+2}$ and $3\omega_i-2\omega_{i+1}$ for n carrier input and his expressions are given as

$$V_{21} = \frac{3}{4}a_3\left(\frac{2P_{il}}{n}\right)^{\frac{3}{2}}\{1+\frac{2a_5}{3a_3}\left(\frac{P_{il}}{n}\right)[12.5+15(n-2)]$$

$$+105\frac{a_7}{a_3}\left(\frac{P_{il}}{n}\right)^2\left[(n-2)(n-3)+\frac{13}{6}(n-2)+\frac{7}{12}\right]+\ldots\}$$

$$V_{1,1}=\frac{3}{2}a_3\left(\frac{2P_{it}}{n}\right)^{\frac{3}{2}}\{1+10\frac{a_5}{a_3}\left(\frac{P_{it}}{n}\right)\left[\frac{3}{2}+(n-3)\right]$$

$$+210\frac{a_7}{a_3}\left(\frac{P_{it}}{n}\right)^2\left[1+\frac{7}{4}(n-3)+\frac{1}{2}(n-3)(n-4)\right]+\ldots\} \qquad \ldots(3.36)$$

$$V_{3,2}=\frac{5}{8}a_5\left(\frac{2P_{it}}{n}\right)^{\frac{5}{2}}\left\{1+\frac{49a_7}{4a_5}\left(\frac{P_{it}}{n}\right)\left[1+\frac{12}{7}(n-2)\right]+\ldots\right\} \qquad \ldots(3.37)$$

Here each expression is valid only when n-x is positive or zero. It should [illegible] the intermodulation compression factor represents the intermodulation resulting from higher order nonlinearities. It may be seen that the amplitude of the third order intermodulation product $\omega_r+\omega_{r+1}-\omega_{r+2}$ is 3 db higher than that of the type $2\omega_r-\omega_{r+1}$. Further since $|a_5|<<|a_3|$ and also the compression *factor for the fifth order intermodulation product decreases rapidly with*

$$\left(\frac{C}{I}\right)_r=\frac{B_n^2}{D_{2,1}(r,n)V_{2,1}^2+D_{1,1,1}(r,n)V_{1,1,1}^2} \qquad \ldots(3.38)$$

where $D_{2,1}$ *represents* the number of third order intermodulation products that fall right on the rth carrier and is for the $2\omega_r-\omega_{r+1}$ third order type. It is expressed as

$$D_{2,1}(r\,n)=\frac{1}{2}\left\{n-2-\frac{1}{2}[1-(-1)^n](-1)^r\right\} \qquad \ldots(3.39)$$

Similarly $D_{1,1,1}$ (r,n) is for the $\omega_r+\omega_{r+1}-\omega_{r+2}$ third order type and is expressed as

$$D_{1,1,1}(r\,n)=\frac{r}{2}(n-r+1)+\frac{1}{4}[(n-3)^2-5]$$

$$-\frac{1}{2}[1-(-1)^n](-1)^{n+r} \qquad \ldots(3.40)$$

It would be worthwhile to mention here that the total n carrier outpu power $nB_n^2/2$ is always smaller than the total single carrier output $B_1^2/2$ because power is lost in itermodulation products. This is shown in Fig. 3.5. The output backoff BO_0 of TWTA is the indicator of its power drive level and is defined as the ratio of the peak single carrier output power ($n = 1$) to the total desired n - carrier output power.

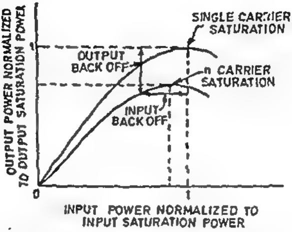


Fig 3.5. Power lost due to Intermodulation Products in n Input Carrier

Thus

$$BO_0 = \frac{B_{1,\text{sat}}^2}{nB_n^2} \qquad \text{...(3.41)}$$

Incase the normalized amplitude transfer characteristics (Fig. 3.4) is used $B_{1,\text{sat}} = 1$ and then

$$BO_0 = \frac{1}{nB_n^2} \qquad \text{...(3.42)}$$

The input backoff is defined as the ratio of the single carrier input power which yields the saturated output power $B_{1,\text{sat}}^2/2$ to the total input power of the n carrier input at its operating point. Thus,

$$BO_i = 10 \operatorname{Log} \frac{B_{1,\text{sat}}^2/2}{P_{ti}}$$

$$= 10 \operatorname{Log} \frac{0.5}{P_{ti}} \qquad \text{...(3.43)}$$

Normally, $B_{1,\text{sat}}^2/2$ is given. For example a 15W TWTA means $B_{1,\text{sat}}^2/2 = 15\text{W}$. Thus BO_0 may be easily calculated.

Westcott [3] has also analysed the effects of intermodulation products taking into account the phase nonlinearities of TWTA. He has shown that to a

$\omega_1 + \omega_2 - \omega_3$ products. Here K_θ is the amplifier amplitude modulation-phase

represents the carrier to adjacent satellite interference ratio then the total carrier to noise plus interference ratio of the fdm system is given as (in line with Eq.(2.33)).

$$\frac{C}{N}=\left[\left(\frac{C}{N}\right)^{-1}+\left(\frac{C}{I}\right)_{im}^{-1}+\left(\frac{C}{I}\right)_{r}^{-1}+\left(\frac{C}{I}\right)_{a}^{-1}\right]^{-1} \qquad ...(3.44)$$

Similarly if $(C/N)_u$ is the carrier to noise plus interference ratio in the uplink, $(C/N)_d$ is the carrier to noise plus interference ratio in the down link, (C/I) is the carrier to intermodulation, ratio, then

$$\frac{C}{N}=\left[\left(\frac{C}{N}\right)_{u}^{-1}+\left(\frac{C}{N}\right)_{D}^{-1}+\left(\frac{C}{I}\right)^{-1}\right]^{-1} \qquad ...(3.45)$$

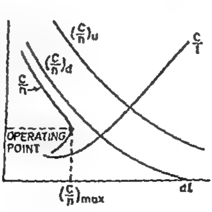


Fig 3.6. Plot of (C/N) Ratios as a Function of BO_0.

backoff BO_0, therefore the carrier to noise plus interference ratio in the uplink is also a function of BO_0. Hence the total carrier to noise plus interferece ratio of the satellite link is a function of the TWTA backoff BO_0 and by Eq.(3.45) it possesses a maximum value with respect to an optimum BO_0. Fig. 3.6 shows [illegible]

3.10. Energy Dispersal in FM/FDM Signal

In a fm transmitter when the input modulating signal is absent, the transmitter radiates all of its power at the carrier frequency. With the modu[illegible] the lar[illegible] transm[illegible] minimum spectral power density occurs with the maximum modulation amplitude. This condition is called *full loading*. Since terrestrial microwave [illegible] symmetric triangular waveform to the modulating waveform before modulation. This additional symmetric voltage waveform is called the [illegible]

signal has a constant amplitude and frequency of 30 Hz. In general the amplitude of the dispersal signal for multichannel telephone transmission is determined by finding the frequency shift (peak deviation) Δf that dispersal waveform must cause.

Miya[6] has discussed the calculations of Δf for a dispersal signal. Consider a FDM/FM analog telephone [illegible]

$$W(f) = \left(\frac{c}{d\sqrt{2\pi}}\right) \exp\left[-(\Delta F)^2/(2d^2)\right] \qquad ...(3.46)$$

where ΔF is the difference between the unmodulated carrier frequency f_c and f. At full loading the density is $W_{min}(f)$ and is given by

$$W_{min}(f) = \left[\frac{c}{d\sqrt{2\pi}}\right] \exp\left[-(\Delta F)^2/(2d_m^2)\right] \qquad ...(3.47)$$

where d_m is the fully loaded rms multichannel deviation. At no loading the density W_{max} is determined by the deviation ΔF_{max}, which the maximum dispersal waveform causes. Assuming that the triangular dispersal [illegible] simply spreads the carrier power C uniformly over a band that extends [illegible] on either side of the carrier frequency, then

$$W_{max} = \frac{c}{2\Delta F_{max}} \qquad \text{...(3.48)}$$

The usual practice is to choose $W_{max} = W_{mn}(0)$, which gives

$$D\,F_{max} = \frac{C}{2W_{mn}(O)} = d_m\left(\frac{\pi}{2}\right)^2 \qquad \text{...(3.49)}$$

The rms multicarrier deviation d_m equals the loading factor of Eq.(3.16) multiplied by the rms test tone deviation Δf_{rms} of the link. Thus from d_m one may calculate the maximum deviation F_{max} that the dispersal waveform would be capable of producing. For less than full loading ($d < d_m$), ΔF is obtained by the following relation

$$\frac{1}{\sqrt{2\pi}}\frac{\Delta F}{d_m} = \frac{1}{\sqrt{2\pi}}\int_o^{\frac{\Delta F}{d_m}\cdot\frac{d_m}{d}} e^{-x^2/2}dx \qquad \text{...(3.50)}$$

where the integrals may be evaluated from readily available tables.

3.11. Review Questions

1. [illegible]
2. What is meant by multiplexing the signals ? In analog means of satellite communication which multiplexing technique is used and why ? What are the main reasons for using multiplexing techniques in satellite communication ?
3. What is meant by 'threshold' in FM detector ? Explain fm improvement and derive the S/N ratio for SCPC signals
4. What is loading factor and how does it affect the fm/fdm signal transmission ?
5. Compare the performance of fm/fdm SCPC and CSSB systems
6. How does the non-linear behaviour of a TWTA affect the operational characteristics (C/N) of a satellite link? What are the intermodulation products and how are these generated with TWTAs ? Discuss the carrier to intermodulation for amplitude nonlinearities of TWTA ?
7. What is 'energy dispersal' ? Discuss its applications for satellite communication. Also, explain the dispersal signal
8. [illegible]
9. For a 60 channel FDM system with a maximum baseband frequency of fm = 252 kHz and a specified top-channel signal-to-noise ratio S/N = 52 dB find out the bandwidth. [illegible]
10. Explain analog television transmission through satellite. Write down the expressions for S/N ratio calculation for satellite TV links.

3.12. References

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FOUR

Digital Signal Transmission

4.1. Advantages of Digital Communication

The advantages of digital communication have already been mentioned [illegible] digital techniques quite successful.

The telegraph was the first modern form of digital communication but because of its much smaller bandwidth, voice telephone communication [illegible] nication is basically the analog [illegible] of today's data communication. In order to access the computers from a distance, mechanisms were developed worldwide for transmitting data over the analog voice communication systems. But due to better reliability and higher quality, digital voice telecommunication has become widespread over [illegible] The cost of transmitting the signal [illegible] cost of private voice networks by significant factors, ranging from 10% to 30% for many large organisation.

4.2. Byte

A bit is an abbreviation for binary digit. Byte represents the storage position in the main memory. It represents one alphanumeric character in the [illegible] eight bits long. Thus byte is a set of bits

may be partioned into four 8 bit byte or four 8 bit characters. The bytes may be grouped together to store a large integer or real number but for

communications such as line printers, terminals, tape readers must conform to the same standard. The software used to interpret data has also to follow suit. To minimize the transmission errors various codes are used.

4.3. Baud

A baud is the unit of signalling speed and represents the speed of a communication channel. Historically it is a contraction of the surname of the Frenchman JME Baudot whose five bit code was adopted by the French telegraph system in 1877. Formally, a baud was defined as the number of codes

4.4. Elements of Digital Communication System

of the components as shown in Fig 4.1. As compared to its analog counterpart, it has additional units of encoder and decoder and so here a knowledge of transmission codes, transmission rate, transmission synchronization, error detection and correction and transmission efficiency is needed. It would be worthwhile to note that the communication systems may be simplex or half duplex or full duplex ones. In the simplex systems communication is one way. In half duplex system communication is allowed in either direction at a time. In full duplex case communications may be done in both directions simultaneously.

itude cond. The

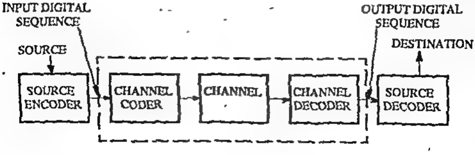

Fig. 4.1. Elements of a Digital Communication System

digital telephone exchange. In United States and most of the European countries, digital transmission is widely utilised and much of the world uses digital transmission links operating at 2.048 megabits per second.

4.5 Digital Baseband Signals

The digital baseband signals are logically transmitted (serially

commonly used in communication because it is so simple to generate, detect and use. Since the two levels are fixed by the system that generates them, no

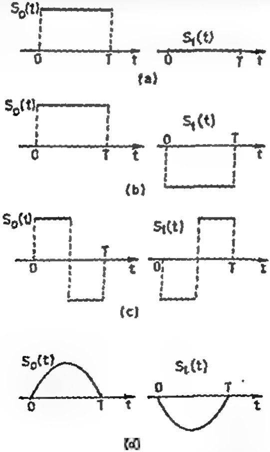

Fig 4.2. Typical Examples of Digital Baseband Signals (*a*) and (*b*) Rectangular Pulse Waveforms, (*c*) Split Phase Pulse Waveform (*d*) Sine Pulse Waveform

information can be implied by the voltage level. The information has to be contained or encoded in the pattern of the levels with time. Typical example is as that of *Morse code*.

Fig 4.2 shows some kind of digital baseand signals. Thus if S_k $(k = 0, 1, ...$

denoted by E. For two signals $S_k(t)$ and $s_j(t)$, their inner product (S_k, S_j) is defined as

$$(S_k, S_j) = \int_{-\infty}^{\infty} s_k(t)\, s_j(t)\, dt \qquad ...(4.1)$$

The signal sets are of two kinds namely the *orthogonal signal sets* and

inner product is $(s_o, s_1) = -E$.

of a full period of a sine wave. It may be noted that there are several binary and M ary baseband signal sets which can not be described in terms of a single waveform of duration T.

The mathematical representation of digital baseband signal is being done in the following way. Let m_n denote the message produced by the source during the nth interval $[\,nT, (n+1)\,T]$, then the sequences of the messages to be sent to the receiver is

$$(m_n) = \ldots, m_{-1}, m_o, m_1, m_2, \ldots \qquad ...(4.2)$$

If the source output in the nth interval is k, $m_n = k$ and the transmitted signal is equal to $s_k(t-nT)$ for $nT \leq t\ (n+1)\,T$. The signal $s(t)$ is actually a sequence of replica of basic waveform and so one may have

$$s(t) = \sum_{n=-\infty}^{\infty} s_{mn}(t-nT) \qquad ...(4.2)$$

sets on $[O, T]$,

$$s_k(t) = A d_k\, v(t) \qquad ...(4.4)$$

where A is a constant and represents the signal amplitude, d represents set of data variables, $\{d_k : k = 0, 1, \ldots M-1\}$, the subscript k represents the kth signal in the set of d_k. In order to define the transmitted signal, the message sequence

(m_n) is represented by the corresponding sequence (b_n) of data variables and then the latter sequence is defined by $b_n = d_k$ if $m_n = k$. Then the transmitted signal is defined as

$$s(t) = \sum_{n=-\infty}^{\infty} A b_n\, v(t - nT) \qquad \ldots(4.5)$$

In the analysis of various digital modulation techniques, the above form of digital baseband transmitted signal is normally used.

4.6. Digital Modulation Techniques

4.6.1. Amplitude Shift Keying (ASK)

circuits. Thus if the carrier is represented by $e = E_c \sin(\omega_c t + \phi)$ then the modulated signal using on-off keying (ASK) may be expressed as

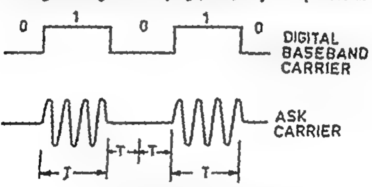

Fig. 4.3. Principle of Amplitude Shift Keying

$$s(t) = a(t) \cdot E_c \mathrm{Sin}(\omega_c t + \phi) \qquad \ldots(4.6)$$

where $a(t)$ is the baseband signal represented as $a(t) = \sum_{n=-\infty}^{\infty} b_n\, v(t - nT)$.

A modification of ASK is the *quadrature* ASK (QASK) which is also known as quadrature AM (QAM). The QASK signal is of the form

$$s(t) = a_1(t)\, E_c \sin(\omega_c t + \phi) + a_2(t)\, E_c \cos(\omega_c t + \phi) \qquad \ldots(4.7)$$

where $a_1(t)\,E_c \sin(\omega_c t+\phi)$ represents inphase component and $a_2(t)\,E_c \cos(\omega_c t+\phi)$ represents quadrature component. Each of these two components of the QASK signal is an ASK signal with pulse duration T_s (where $T_s = 2T$ if the source produces binary digits at the rate of one bit every T seconds. Thus for binary ($m = 2$) $a_1(t)$ and $a_2(t)$ signals the in-phase and quadrature signals are binary ASK signals of $(1/T_s)$ bits per second. In that case, the total data rate for QASK signal would be $\frac{2}{T_s} = \frac{1}{T}$ bit per second.

4.6.2. Phase Shift Keying

In the phase shift keying, the mark and space signal are represented by 180^0 phase shift and zero phase shift respectively. The amplitude of the *RF* carrier is kept fixed. The most important kind of phase shift keying technique is *binary phase shift keying* (BPSK). Here the transmitted *rf* signal is a sinusoid of fixed amplitude but its phase has been shifted by $+\frac{\pi}{2}$ radians or $-\frac{\pi}{2}$ radians d[illegible]
c
c
transmitted at the channel rate of $f_b = \frac{1}{T}$ bits per second (or the bandwidth = $2f_b$). Thus if the transmitted sinusoid is of amplitude A, it has a power $P_s = \frac{1}{2}A^2$ so that $A = \sqrt{2P_s}$. Thus the transmitted signal is either

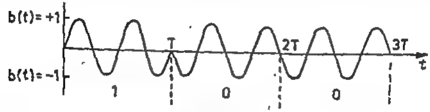

Fig. 4.4. Binary Phase Shift Keying Data Rate 1/T Bits per second

$$S_{bpsk}(t) = \sqrt{2P_s}\cos(\omega_c t) \quad \text{...(4.8)}$$

or

$$S_{bpsk}(t) = \sqrt{2P_s}\cos(\omega_c t+\pi) \quad \text{...(4.9)}$$

$$= -\sqrt{2P_s}\cos(\omega_c t) \quad \text{...(4.10)}$$

$$= b(t)\cos(\omega_c t) \quad \text{...(4.11)}$$

where $b(t) = +1V$ represents the logical level 1 and $b(t) = -1V$ represents the logical level O. It may be noted that the binary PSK may be considered as

amplitude modulation by a sequence of rectangular pulses of duration T with amplitudes +1 and -1.

4.6.3. Quadrature Phase Shift Keying QPSK and M - ary PSK

In the BPSK the channel bandwidth is $2f_b$ where $f_b = \frac{1}{T}$ (T is the bit duration).

according to the value of the modulating voltage. The transmitted signal QPSK for the interval $[nT, (n+1)T]$ can be written as

$$s(t) = A\cos\{\omega_c t + \theta_k\} \qquad \ldots(4.12)$$

where k denotes the message to be sent in the nth interval ($k = 0, 1, 2$ or 3). The four different values of θ_k must be separated by $\frac{\pi}{2}$ radians. For example one may have $\{\theta_k : k = 0, 1, 2, 3$ as the set $\left\{0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}\right\}$ or the set $\left\{\frac{\pi}{4}, \frac{3\pi}{4}, \frac{5\pi}{4}, \frac{7\pi}{4}\right\}$. It is essential that the phase difference of $\frac{\pi}{2}$ is maintained. Eq.(4.13) may also be written as

$$s(t) = A\cos[\omega_c t + \theta(t)] \qquad \ldots(4.13)$$

where $\theta(t)$ represents phase modulation and is a sequence of rectangular pulses of duration T and amplitude $\left(\frac{\pi}{2}\right)b_n$ with $b_n = 0, 1, 2$ or 3. Fig. 4.5 indicates the QPSK signal for the data sequence in $b_0 = 0$, $b_1 = 2$ and $b_2 = 3$. Here the data rate is $2/T$ bits per second.

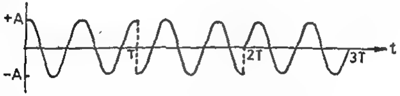

Fig 4.5. Example of QPSK with Data Rate 2/T Bits per second

The power in QPSK signal is $A^2/2$, just as for BPSK and so the energy per pulse is $E = A^2T/2$. The QPSK gives 2 bits of data per pulse and therefore the energy per bit for QPSK is $E_b = \frac{A^2T}{4}$ which is one half of the energy per bit for BPSK for the same pulse duration T. Thus when QPSK compared with BPSK for the same data rates, BPSK requires twice the bandwidth of QPSK. However, if the two signals have the same data rate and equal power, they also same energy per data bit. It would be worthwhile to mention here

that there are also some other modifications of BPSK such as differential phase-shift keying (DPSK), differentially-encoded PSK (DEPSK), offset

modulating voltage that determines the transmitted phase. A generalization of BPSK has also been carried out that is widely termed as *M-Ary PSK* and-now-a days hardware to accomplish such M -ary communication is available. The principle of M -Ary PSK is explained below:

We have seen above that in BPSK, each bit is transmitted individually. Depending on whether $b(t)$ is logic O or logic 1, one transmits one or another of a sinusoid for the bit time T_b, the sinusoids differing in phase by $\frac{2\pi}{2} = 180°$. In QPSK the two bits are lumped together and depending upon which of the four two-bit words develops, one transmits one or another of four sinusoids of duration $2T$, the sinusoids differing in phase by amount $\frac{2\pi}{4} = 90°$. In M-ary PSK, the scheme has been extended. On lumping together the N bits so that in this N-bit *symbol* extending over the time NT, there would be $2^N = M$ possible symbols. Thus, $N = 1$ or $M = 2$ represents binary and $N = 2$ or $M = 4$ represents quaternar. Now let these N bit symbols be represented by sinusoids of duration $NT = Ts$ which differ from one another by the phase $2\pi/M$. Then the M-ary PSK waveforms could be represented as

$$S_m(t) = \sqrt{2P_s}\cos(\omega_c t + \phi_m),\ m = 0, 1, ---M-1) \qquad ...(4.14)$$

With the symbol phase angle given by

$$\phi_m = (2m+1)\pi / M \qquad ...(4.15)$$

The bandwidth is therefore

$$B = \frac{2}{T_s} = 2f_s = \frac{2}{NT} = \frac{2f_b}{N} \qquad ...(4.15)$$

It is thus evident that as one increases the number of bits N per symbol

4.6.4. Binary Frequency Shift Keying (BFSK)

In the binary frequency shift keying which is also sometimes called simply as frequency shift keying (FSK) employs two different carrier frequencies which are switched ON and OFF

$$s_{\bar{s}}(t) = \sqrt{2P_s}\cos(\omega_c \pm \Omega)\, t \qquad ...(4.16)$$

showing the two angular frequencies of $\omega_c+\Omega$ and $\omega_c-\Omega$ with Ω a constant offset from the normal carrier frequency ω_c. The quantity Ω is called the

(binary digit). The bandwidth of BFSK signal is $4f_b\left(f_b=\frac{1}{T}\right)$ and is twice the bandwidth of BPSK.

A generalization of binary FSK can be carried out to M-ary FSK. The bandwidth in M-ary FSK would be

$$BW = 2Mfs \qquad ...(4.17)$$

where $\qquad f_s = f_b/N$ and $M = 2_N$. Thus

$$BW = 2^{N+1}f_b/N \qquad ...(4.18)$$

Thus M-ary FSK requires a considerably increased bandwidth in comparison with M-ary PSK. However, it has been established that the

4.7. Satellite Digital Link Design

usually stated as a single number-for example 1×10^{-4} or .0001. BER is analogous to SNR of the analog link.

The bit error arises due to symbol errors which arise mainly due to thermal noise, external interference and intersymbol interference. In case if only thermal noise is considered then the symbol error rate (SER) or symbol error probability may be calculated unambiguously from (E_s/N_o), the energy per symbol in joules divided by the noise density in W/Hz measured in the IF bandwidth at the demodulator input. The higher the value of the the (E_s/N_o),

$$E_s = CT_s = \frac{C}{R_s} \qquad ...(4.19)$$

where R_s is the symbol rate in symbols/second. The noise-density (noise power per hertz) N_0 is the received noise power N divided by the IF bandwidth at the demodulator input

$$N_0 = \frac{N}{B} \qquad ...(4.20)$$

From these two equations

$$\frac{C}{N} = \left(\frac{E_s}{N_0}\right)\left(\frac{R_s}{B}\right) \qquad ...(4.21)$$

Similarly if E_b represents the bit energy and R_b represents the bit rate then

$$\frac{C}{N} = (E_b / N_0)\,(R_b / B) \qquad ...(4.22)$$

In satellite communications the quantity (C/N) is directly evaluated (Chapter 2). Once the C/N is known and the bandwidth of the receiver is selected, E_s/N_o or E_b/N_o can be calculated. From Eqs.(4.21) and (4.22) it is

rate R_s reached its maximum value, the curve saturates. The left region is referred to as the *power limited region* ; the saturated region at the right is called the *bandwidth-limited region*. It may be noted that in order to recover

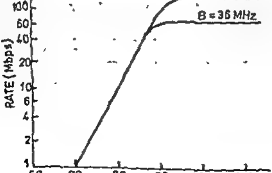

Fig 4 6. Variation of Rate R as a Function of C/N_0

a plot of these expressions.

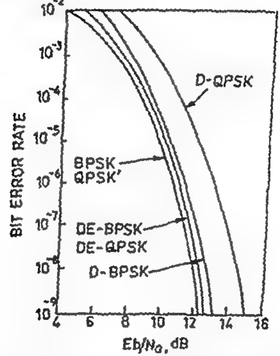

Fig 4.7. Ideal bit error rate performance of various digital modulation schemes

Table 4.1. Ideal Error Rate Performance of Various Digital Modulation Schemes

Modulation Technique	*Ideal bit error rate performance*
MSK, BPSK/QPSK	$P = \frac{1}{2} \operatorname{erfc} \sqrt{E_b/N_o}$
Orthogonal FSK with coherent detection	$P = \frac{1}{2} \operatorname{erfc} \sqrt{E_b/N_o}$
Orthogonal FSK with noncoherent detection	$P = \frac{1}{2} \exp(-E_b/2N_o)$
D - PSK	$P = \frac{1}{2} \exp(-E_b/2N_o)$

For M-ary modulation schemes the error rate performance is specified in f symbol error rate P_s but for BPSK bit and symbol errors are the same

thing. For the symbol error probability (p_s) less than 1, the error rate performance is given as

$$P \cong \frac{P_s}{\log_2 M} \qquad \ldots(4.23)$$

For QPSK, M = 4 and then $P_s = 2P$. Thus the bit error rate for QPSK is smaller than the symbol error rate. It may be seen from Fig. 4.7 that QPSK has higher BER than BPSK but since QPSK carries twice as much data as BPSK for the same RF bandwidth and using QPSK can double the communication capacity (and renew earning power) of a transponder. It would be worthwhile to mention here that CCIR recommendations also exist regarding telephony services. Thus according to CCIR recommendations 522-1, 1982 the BER should not exceed : 10^{-6} for more than 20 per cent of any month (10 [illegible]

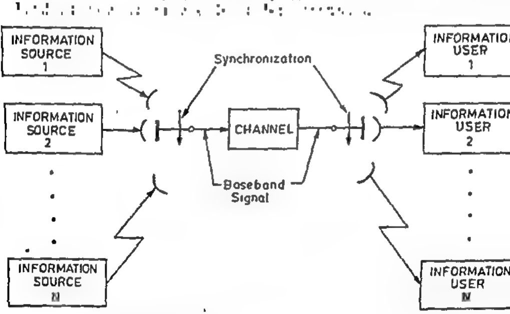

Fig 4.8. Principle of TDM

4.8. Time Division Multiplexing

As mentioned in [illegible]

of duration $T = T_s/M$ where T_s is $1/f_s$ (baseband signal frequency o transmission). Actually this time slot T for individual channel consists of th [illegible] channels are sampled at rate f_s.

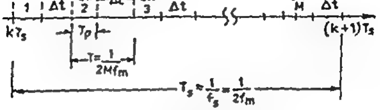

Fig 4.9. Interleaving of M Channels Pulses on one Sampling Time Frame (Ts)

Thus $$T_p \le \frac{T_s}{M} - \Delta t = \frac{1}{2Mf_m} - \Delta t \qquad ...(4.24)$$

The TDM wave after interleaving of the M PAM waves is therefore expressed by

$$v_M(t) = \sum_{i=1}^{M} v_i(t) \qquad ...(4.25)$$

It may be noted that as shown in Fig. 4.8 the baseband TDM signal also includes the synchronization signal

$$C_s(t) = \cos \omega_s t \qquad ...(4.26)$$

Thus the baseband signal $v(t)$ is

$$v(t) = v_M(t) + C_s(t) \qquad ...(4.27)$$

The sync signal is used to synchronise the commutation (sampling), pulse [illegible]

bits that repeat a known pattern.

4.9. US T_1 24-Channel System

The T_1 channel system was developed by Bell System USA for TDM tion in terrestrial microwave links. This is the best example to understand

in the 125 μs frame interval. Thus, the bit rate in T_1 24 channel system is 193 bits divided by 125 μs or 1.5440 megabits.

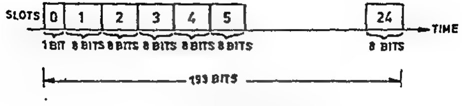

Fig 4.10. Slots in bell T_1 Frame

As mentioned the slot O is the responsible for synchronisation information. This is done by a

constitutes

100011011

The group

the first fra

4.10. Review Questions

1. How is the digital satellite communication different from analog satellite communication ? Explain the relative merits and demerits of these two methods.
2. What are the various methods of digital modulation techniques and which one is mostly used in digital satellite communications ? Explain with reasons.
3. What is meant by bit error rate ? Tell its optimum acceptable value for digital satellite communication ? What is its counterpart in an analog link ?
4. Derive an expression for a digital satellite link and explain as to how is it dependent on the system bandwidth ?
5. What is symbol error rate ? How is it different from bit error rate ? For which ary modulation symbol error is similar to bit error rate and why ? What happens to the case of M-ary modulation ?
6. What is meant by error rate performance of a system ? How do you calculate the error rate performance for MSK, BPSK, QPSK, orthogonal FSK and DPSK system ?
7. What is time division
8.

(9). What is T_1 24 channel frame? Explain its operation with reference to terrestrial microwave links and digital satellite links. What is its equivalent CCITT standard?

10. Explain the digital baseband signals and write down mathematical expression for a digital waveform before modulation.

4.11. Suggested References

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FIVE

Multiple Access Techniques

5.1. Introduction

Multiple Access Techniques allow interconnection among large number of earth station terminals simultaneously via satellite. Alternately, with multiple access techniques any one earth station can communicate with all

earth station and therefore to have the best use of transponder's capacity, it must be allocated to other earth stations. This allocation must be wisely done

In the multiple access technique, the concepts of multiplexing techniques used in various communication systems are used. The frequency division

multiple access (tdma) techniques. There has also been a *random access multiple* scheme which was used in ALOHA systems. With the development

techniques, the access of earth stations to the satellite may be based on the fixed or demand basis. In the fixed case, the proportion allocated to each earth station is fixed in advance

access techniques are quite efficient techniques and these will be explained in the next chapter.

5.2. Time Division Multiple Access (TDMA)

[illegible]

during their traffic transmission have access to the entire bandwidth of the

[illegible]

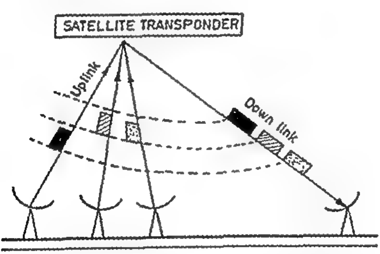

Fig. 5.1. Principle of Time Division Multiple Access

The number of voice channels in a TDMA system is given by

$$n = (1/r)(R - NP/T) \qquad ...(5.1)$$

where

r = Voice channel bit rate
R = satellite channel bit rate (power or band limited)
N = number of bursts in a frame
P = number of digits in the preamble
T = frame period.

Some of the terms in Fig (5.1) ...
TDMA frame st...
FDMA. The requ...
FDMA systems a...
is used, since only ... passes through the transponder at any one time, the output *twt* tube may be operated at saturation with a consequent increase in satellite *eirp* and no intermodulation will be produced. Also, for highly busy/density traffic TDMA is most efficient. Some of the other advantages of TDMA over FDMA are further discussed in Section 5.8.

5.3. TDMA Frame Structure

Fig. 5.2 indicates a typical frame structure. As already mentioned in a TDMA network each ...

... station is termed *primary reference station* (PRS). Similarly the another reference burst serves as *secondary reference burst* (SRB) and the corresponding earth station would be ...

TDMA ...
of PRB ...
TDMA ...

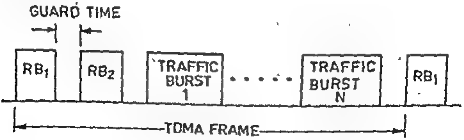

Fig 5.2. The TDMA Frame S...

In order to ensure that there may never be any overlapping between

993 ns or around 1 μ_s .

It should be noted that the minimum frame time in TDMA is 125 μ_s required by a voice channel sampled at the standard 8 KHz rate. The maximum frame time is arbitrary, provided that each frame contains one sample from each voice channel for each 125 μ_s of frame duration. Thus the frame time

SBS	15 ms
Intelsat V	2 ms
Advanced West Star	125 - 750 μ_s
Telecom 1	20 ms
Intelsat VI	2 ms

5.4. TDMA Burst Structure

to the other.

The carrier and clock recovery sequence are the bits or symbols with which each burst begins. These enable the earth station demodulator to recover the carrier phase and regenerate the bit or symbol timing clock for data

The unique word (UW) which is also called the *burst code word* (BCW) serves to mark each frame. [illegible] burst. The unique word is a sequence of ones and zeros and typical lengths [illegible]

[illegible] it has been seen that the larger unique words reduce the probabilities of such errors though there already exist various techniques to reduce the probabilities of such errors.

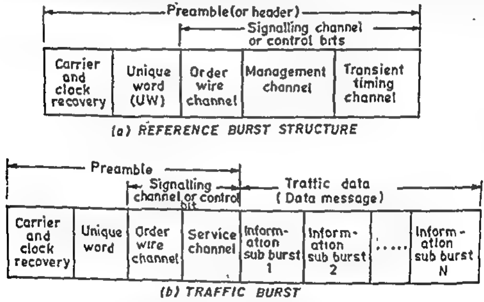

Fig 5.3. TDMA Burst Structure

The signalling channel is present in both the [illegible] The reference burs[illegible] management chann[illegible] consists of only an [illegible] channels of both the reference and traffic bursts carry the voice (telephone) and data [illegible]
stati[illegible]
swit[illegible]
can t[illegible]
The [illegible]
to al[illegible]
such [illegible]
coor[illegible]

time slots of the frame allocated to the stations *i.e.* the burst positions. It also identifies the position, length and source or destination stations corresponding to subbursts in the bursts. Whenever, the reference station wants to obtain a status report (monitoring) the management channel would also carry monitoring and control messages to the traffic stations. The transmit timing channel carries the acquisition and synchronization information to the traffic stations and enables them to adjust their transmit burst timing so that transmitted bursts arrive at the satellite transponder within the correct time [illegible]

bursts.

[illegible]

5.5. TDMA Frame Efficiency

The TDMA frame efficiency (η) depends on the ratio of the time devoted to transmission of information bits in the frame to the total frame length and is thus defined as

$$\eta = 1 - \frac{\Sigma t}{T_F} \qquad \ldots(5.2)$$

where Σt represents the sum of all the guard times and preambles including the reference burst and is also expressed as

$$\Sigma t = \frac{(n+2)P}{R} \qquad \ldots(5.3)$$

[illegible]

(5.2) it is evident that to have better frame efficiency, should be small and [illegible]

earth station equipment. Moreover, transmission delay increases with the e length. It should be noted that the current frame efficiency in various ital communication satellites is of the order of 0.9.

Once the frame efficiency is known the number of telephone channels that may be supported by a TDMA system is

$$v = \frac{R}{r\eta} \qquad \ldots(5.4)$$

where r is the bit rate of a voice channel. Thus if $n = 12$ transmitting stations, $P = 680$, $T_F = 2$ ms, $r = 64$ K bit/s, $R = 120.832$ m bit/s and $\eta = 96\%$, the number of voice channels $v = 1813$.

5.6. TDMA Superframe

It has been found that if the sequential frames are combined in an orderly manner, the resulting combination reduces the overheads considerably, thus [illegible]

individually by a single message. In other words station 1 would be addressed [illegible]

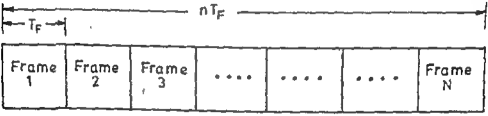

Fig 5.4. TDMA Superframe

To identify the frames in a superframe a frame identification number is [illegible]

transmitted at the superframe rate. This will be made clear in the next chapter while dealing with DA-TDMA.

5.7. TDMA Frame Acquisition and Synchronization

in any case. This accuracy in the transmission and the reception of time bursts may only be achieved by the processes called *frame acquisition* and *frame*

synchronization processes may be grouped as *receive frame acquisition (RFA)*, transmit *frame acquisition (TFA)*, *receive frame synchronization*, *transmit frame synchronization*.

in the satellite movement such as peak to peak altitude variation, east-west

positions as they arrive at the transponder. Therefore a correct synchronization is necessary in every roundtrip delay to avoid errors. It may be noted that the Dopplershift is of the order of 40 ns/s.

The synchronization is achieved by introducing a transmit frame delay D_N to mark the transmit frame timing of station N such as

$$D_N = MT_f - \frac{2d_N}{C} \qquad \ldots(5.5)$$

where T_f is the frame period, d_N is the distance between the satellite N, C is the velocity of light and M is the smallest integer chosen such that $D_N \geq O$ for

synchronization processes. In one of them, D_N is determined by the earth station directly from monitoring its own transmission and the method is called the *closed loop control* (or some times *loop back* method. In other technique

burst unique word and the traffic burst unique word, computes the error and determines a new value for the delay D_N. Thus if $E_N(i)$ is the observed error then the corrected delay $D_N(i+1)$ would be

$$D_N(i+1) = D_N(i) - E_N(i) \qquad \text{...(5.6)}$$

This method of synchronization is not possible for a little complex TDMA systems such as those of multibeam or satellite switched TDMA systems. It also does not provide for the sort of synchronised network control that can monitor the synchronization of all the stations and automatically shut down any network members who are out of sync and unaware of the problems they are causing.

In the open loop synchronization such as that of co-operative synchronization used in Intelsat TDMA systems, a control station listens to the bursts and sends timing instructions back to each transmitting station. The main thing in the instructions is the time delay D_N. In the Intelsat TDMA

for no more transmission from that particular station.

As in the synchronization technique the frame acquisition techniques may be either *closed loop acquisition* or *open loop acquisition*. Closed loop acquisition is obtained by transmitting either a low power burst or a pseudo

be mentioned again that acquisition is performed prior to synchronization so as to bring the station into synchronism with an operating TDMA network.

5.8. TDMA as Compared to FDMA

(i) FDMA is not suitable for the increased system traffic because of the impairments due to intermodulation products. In TDMA since only one burst resides in the transponder at any given instant, degradation caused by intermodulation distortion is avoided. The traffic capacities achieved in a typical transponder for FDMA and TDMA

accesses are co

of accesses inc

intermodulatio

modified between nodes simply by changing the duration and position of each burst in the TDMA frame. This is quite easier especially if the computer control is used for the purpose.

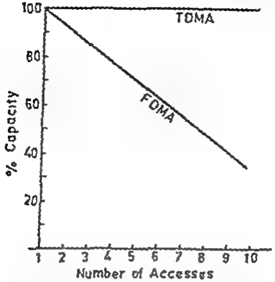

Fig 5.5. Transponder Capacity for FDMA and TDMA Versus Number of Accesses

It would be of importance to mention here that the above advantages of TDMA were recognized early by INTELSAT. COSMAT laboratories had built their experimental systems in the late 1960s and had developed the

designed as per their requirement.

5.9. TDMA Burst Time Plan

It is very essential that the transmission as well as reception of bursts in TDMA must be according to a time plan or *burst time plan* so that there may not be any overlapping of bursts at the satellite transponder. Thus for

and length of the information subbursts within a burst. In other words the burst time plan is simply the traffic assignment within a frame. Following is the usual format for burst time plan.

Message Data

Burst time plan identification
Traffic station identification
Number of Transmit Bursts
Number of receive bursts

Burst Data

Burst identification
Transmit-receive Flag
Transmponder identification
Burst Position
Number of transmit-receive subbursts

Subburst Data

Transmit receive subburst identification
Subburst position
Subburst length

It may be noted that when the network grows or when the network traffic changes, the burst-time plan has to be modified accordingly. Further [illegible]

The adjustment of burst time plan according to the traffic changes is also called the *traffic planning process* which is usually assisted by computer [illegible] an overall burst time plan is determined for an entire network, it is transmitted [illegible] *time plan change method* has been adopted that causes all traffic burst position and duration changes involved in the burst time plan change throughout the network to be synchronised to the same TDMA frame at the satellite. The delay compensation needed to synchronise is assured by the use of D_N whose value may range from 10 to 50 ms.

5.10. Multiple Beam (Satellite Switched) TDMA Satellite Systems

In the previous sections, discussions were on TDMA for satellite [illegible]

[illegible]

The main problem in the interconnection of UBS and DBs in the satellite communication system such as that of Intelsat VI is their interconnectivity. This is achieved by introducing an onboard switching technique also called as *satellite switch*. The corresponding TDMA-system would therefore be called *satellite switched TDMA (SS-TDMA)* system. This satellite switch is actually the dynamic satellite switching that uses a microwave switch matrix on board the satellite. The satellite switch can interconnect the six up beams to the six down beams in accordance with any desired single point connectivity matrix pattern (called a 'switch state') for a dwell interval of programmable location and duration. It should be noted that the satellite switching on board can be done at rf or at baseband. For the rf case microwave switching matrix [illegible]

and an acquisition and synchronization unit provides the time references necessary for tdma operation. Cross bar configurations have been designed to provide bandwidth upto 500 MHz at 4 GHz as already being used in Intelsat VI.

Fig. 5.6 indicates the concept of SS-TDMA used in Intelsat VI. There are three upbeams and three downbeams. The onboard satellite switch control station (or the distribution control unit dcu) programmes the switch matrix to execute a cyclic set of switch states, each consisting of a set of connections between the uplink and downlink beams so that the traffic from various regions is routed to designated regions without conflict. It may be noted that the succession of switch states during a frame period is called the switch state [illegible] the duration of a given switch is selected to accommodate [illegible]

Thus in Fig. 5.6, the SS-TDMA operates as a set or parallel TDMA frames on the uplink which are then switched by a sequence of switch states into a set of parallel TDMA frames on the down link. The time duration for the switch state is of concern for an optimal operation. An optimum set of switch states is one which fulfills the total traffic needs of the network with minimum [illegible] that the maximum number of switch states [illegible]

of SS - TDMA is defined as the ratio of the actually used capacity to the total capacity available from all the transponders.

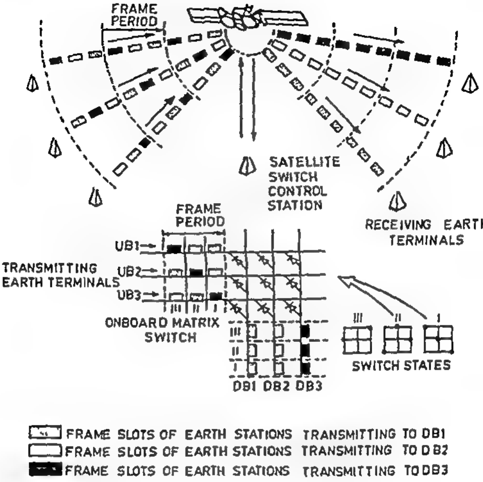

Fig. 5.6. SS-TDMA Concept used in INTELSAT VI

5.11. Beam Hopping (Transponder Hopping) TDMA

In beam hopping TDMA [illegible] efficient and new TDMA systems (such as TDMA etc) used in recent communication satellites are discussed.

5.12. Code Division Multiple Access (CDMA) and Hybrid Access Techniques

In code division multiple access the whole bandwidth of the transponder is used all the time and signals from the users are encoded so that the information from an individual transmitter can be detected and recovered only by a properly synchronized receiving station that [illegible] technique of satellite spread spectrum communications are given. Hybrid multiple access involves CDMA and it will also be studied in Chapter 7.

5.12. Suggested References

The references are same as those of previous chapter.

5.13. Review Questions

1. What is the difference between multiplexing and multiple access techniques ? Are FDM and TDM similar to corresponding FDMA/TDMA respectively ? If not why ? Explain the relative advantages and disadvantages of FDMA and TDMA ?
2. What is burst ? Explain the difference between the reference burst and traffic burst. Explain their positions in a TDMA frame. Explain their structures too.
3. What is guard time ? Mention its value in a typical TDMA system. Explain its importance in TDMA frame efficiency ?
4. What are the overheads in TDMA frame ? Explain their structures How the TDMA frame efficiency is affected by such overheads ?
5. What is TDMA superframe ? Explain its structures. How is it different from a simple TDMA frame ?
6. What is meant by TDMA frame acquisition and frame synchronization ? What is frame delay ? How does it help in carrying out TDMA frame acquisition and frame synchronization techniques ?
7. What is meant by burst time plan ? Explain its structure and importance What are the methods to control the burst time plan ?
8. What is 'spot beam'? Explain the use of multiple spot beams in satellite communication ? How does it increase the capacity of satellite transponder ?
9. What is satellite switching ? Explain the difference between static and dynamic switching ? Discuss the operation of a typical SS-TDMA system ? How is SS-TDMA different from a beam hopping TDMA ?
10. What is CDMA ? In what way is it superior to TDMA ? Mention the potential applications of CDMA ?

SIX

Demand Assignment Multiple Access Techniques

6.1. Introduction

Multiple access techniques as discussed in the previous chapter were based on the division of frequency or the time domain. The channels may be assigned to the users as per requirement. In practice two methods have been [illegible]

In the fixed assignment, a station has periodic access to the channel independent of its actual need. By comparison demand assignment (dynamic assignment) gives the station access to the channel only when it requests access. Logically when most of the users in the communication system do not [illegible]

[illegible] well in the dynamic assignment schemes. Thus the dynamic assignment schemes (DAMA) are more efficient than the preassigned ones.

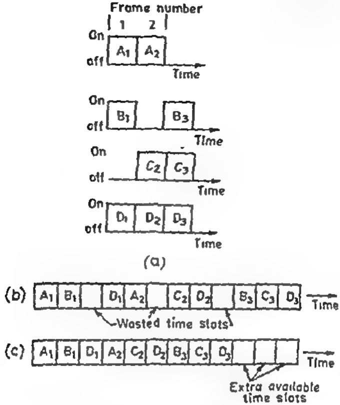

Fig. 6.1. Time Division Multiplexing
(*A*) Data Source Activity Profile, (*B*) Fixed Assignment TDM, (*C*) Possible Utilization With Dynamic Assignment

It may be noted that in any communication system the acutal demand [illegible]

(capacity) of the system would be $\sum_{n=1} W_N$, where $W_1, W_2, ... W_N$ are the band-widths of individuals users. For the dynamic assignment case it may be even $\frac{1}{N}\sum_{n=1}^{N} W_N$. All these indicate the versality and efficiency use of the available frequency spectrum (system capacity) with DAMA.

DAMA [illegible] control mechanism [illegible] thus with the frequency [illegible] is termed as *demand* [illegible] and for TDMA it is *DMA*. There is another method of increasing the capacity of

communication system and this is called *Digital Speech Interpolation (DSI)*. It doubles the number of terrestrial channels carried by a satellite transponder. Some of the other advantages of DAMA would be further cleared in the next section.

6.2. Erlang Call Congestion (Blocking Or B) Formula

[illegible] case [illegible] A.K. [illegible] company. This is based on the fact that when all the channels (say, n) in a [illegible] as

$$p_n = B(n,a) = \frac{a^n / n!}{\sum_{k=0}^{n} a^k / k!} \qquad ...(6.1)$$

Here B(n,a) is termed the Erlang B formula for an n channel group with a *traffic intensity* $a = \lambda / \mu$. λ is the call arrival rate and the calls arrive in a poisson scheme (process). μ is the mean hang up rate. In other words $\frac{1}{\mu}$ represents the average call service time or *holding time*. Thus a is the product of the number of calls per second and the mean service time per call in seconds. The unit of a is *erlang*. Eq.(6.1) is the cornerstone for evaluating the *grade of service* of a voice traffic network. It may be noted that the probability of k arrivals in time interval t is expressed by

$$p_k(t) = \frac{(\lambda t)^k}{k!} \exp(-\lambda t) \qquad ...(6.2)$$

where λ is the call arrival rate.

Eq. (6.1) has been used to study the required number of channels in a fixed assignment as well as in the dynamic assignment schemes. For this purpose, use is made of a table (Table 6.1) called *Erlang B table* that gives tr-

Table 6.1. Erlang B Table : Traffic Intensity Versus Number of Channels and Blocking Probability

	One lost call in					One lost call in			
n	50[a]	100[b]	200[c]	1000[d]	n	50[a]	100[b]	200[c]	1000[d]
1	0 020	0 010	0.005	0 001	51	41.2	38 8	36.8	33.4
2	0.22	0.15	0 105	0 046	52	42.1	39.7	37.6	34.2
3	0 60	0 45	0.35	0.19	53	43.1	40.6	38.5	35.0

Table Contd

	One lost call in					One lost call in			
n	50[a]	100[b]	200[c]	1000[d]	n	50[a]	100[b]	200[c]	1000[d]
4	1.1	0.9	0.7	0.44	54	44.0	41.5	39.4	35.8
5	1.7	1.4	1.1	0.8	55	45.0	42.4	40.3	36.7
6	2.3	1.9	1.6	1.1	56	45.9	43.3	41.2	37.5
7	2.9	2.5	2.2	1.6	57	46.9	44.2	42.1	38.3
8	3.6	3.2	2.7	2.1	58	47.8	45.1	43.0	39.1
9	4.3	3.8	3.3	2.6	59	48.7	46.0	43.9	40.0
10	5.1	4.5	4.0	3.1	60	49.7	46.9	44.7	40.8
11	5.8	5.2	4.6	3.6	61	50.6	47.9	45.6	41.6
12	6.6	5.9	5.3	4.2	62	51.6	48.8	46.5	42.5
13	7.4	6.6	6.0	4.8	63	52.5	49.7	47.4	43.4
14	8.2	7.4	6.6	5.4	64	53.4	50.6	48.3	44.1
15	9.0	8.1	7.4	6.1	65	54.4	51.5	49.2	45.0
16	9.8	8.9	8.1	6.7	66	55.3	52.4	50.1	45.8
17	10.7	9.6	8.8	7.4	67	56.3	53.3	51.0	46.6
18	11.5	10.4	9.6	8.0	68	57.2	54.2	51.9	47.5
19	12.3	11.2	10.3	8.7	69	58.2	55.1	52.8	48.3
20	13.2	12.0	11.1	9.4	70	59.1	56.0	53.7	49.2
21	14.0	12.8	11.9	10.1	71	60.1	57.0	54.6	50.1
22	14.9	13.7	12.6	10.8	72	61.0	58.0	55.5	50.9
23	15.7	14.5	13.4	11.5	73	62.0	58.9	56.4	51.8
24	16.6	15.3	14.2	12.2	74	62.9	59.8	57.3	52.6
25	17.3	16.1	15.0	13.0	75	63.9	60.7	58.2	53.5
26	18.4	16.9	15.8	13.7	76	64.8	61.7	59.1	54.3
27	19.3	17.7	16.6	14.4	77	65.8	62.6	60.0	55.2
28	20.2	18.6	17.4	15.2	78	66.7	63.6	60.9	56.1
29	21.1	19.5	18.2	15.9	79	67.7	64.5	61.8	56.9
30	22.0	20.4	19.0	16.7	80	68.6	65.4	62.7	57.8
31	22.9	21.2	19.8	17.4	81	69.6	66.3	63.6	60.3
32	23.8	22.1	20.6	18.2	82	70.5	67.2	64.5	59.5
33	24.7	23.0	21.4	18.9	83	71.5	68.1	65.4	60.4
34	25.6	23.8	22.3	19.7	84	72.4	69.1	66.3	61.3
35	26.5	24.6	23.1	20.5	85	73.4	70.1	67.2	62.1
36	27.4	25.5	23.9	21.3	86	74.4	71.0	68.1	63.0
37	28.3	26.4	24.8	22.1	87	75.4	71.9	69.0	63.9
38	29.3	27.3	25.6	22.9	88	76.3	72.8	69.9	64.8
39	30.1	28.2	26.5	23.7	89	77.2	73.7	70.8	65.6
40	31.0	29.0	27.3	24.5	90	78.2	74.7	71.8	66.6
41	32.0	29.9	28.2	25.3	91	79.2	75.6	72.7	67.4
42	32.9	30.8	29.0	26.1	92	80.1	76.6	73.6	68.3
43	33.8	31.7	29.9	26.9	93	81.0	77.5	74.3	69.1
44	34.7	32.6	30.8	27.7	94	81.9	78.4	75.4	70.0
45	35.6	33.4	31.6	28.5	95	82.9	79.3	76.3	70.9
46	36.6	34.3	32.5	29.3	96	83.8	80.3	77.2	71.8
47	37.5	35.2	33.3	30.1	97	84.8	81.2	78.2	72.6
48	38.4	36.1	34.2	30.9	98	85.7	82.2	79.1	73.5
49	39.4	37.0	35.1	31.7	99	86.7	83.2	80.0	74.4
50	40.3	37.9	35.9	32.5	100	87.6	84.0	80.9	75.3

[a]Probability of 0.02. [b]Probability of 0.01. [c]Probability of 0.005. [d]Probability of 0.001.

that gives traffic intensity versus number of channels and blocking probability. Infact Table 6.1 has been prepared from Eq.(6.1) itself. It serves like a ready reckoner for the calculation of number of channels for both the fixed

available channels to be assigned on demand. Now, if the same 20 erlang is to be divided equally between 5 destinations then with such a fixed assignment,

ment for a typical blocking probability of .01 and three traffic intensities

TABLE 6.2 : Comparison of Satellite Channel Requirements for Pre-Assignment and Demand Assignments Schemes for Blocking Probabilities of .01

Number of	*Channel Requirement*								
	α = 0.1 Erlang			*α = 0.5 Erlang*			*α = 1.0 Erlang*		
Destinations per Station N	Pre assignment	Demand assignment	Improvement	Pre assignment	Demand assignment	Improvement	Pre assignment	Demand assignment	Improvement
1	2	2	–	4	4	–	5	5	–
2	4	3	1.3	8	5	1.6	10	7	1.4
4	8	3	2.7	16	7	2.9	20	10	2.0
8	16	4	4.0	32	10	3.2	40	15	2.7
10	20	5	4.0	40	11	3.6	50	18	2.7
20	40	7	5.7	80	18	4.4	100	30	3.0
40	80	10	8.0	160	30	5.3	200	53	3.8

assignment which is also used
many destinations with low,
demand assignment which is
serves many destinations with
assignment which is used for
each station serves
and total traffic at eac
per carrier demand

single-channel per burst demand assignment multiple access. It would be worthwhile to mention here that the demand assignment as mentioned above [illegible] techniques are mostly used in packet communication systems and these will be discussed in Chapter 8.

6.3. Demand Assignment Control

In the demand assignment system the most important function is the [illegible]

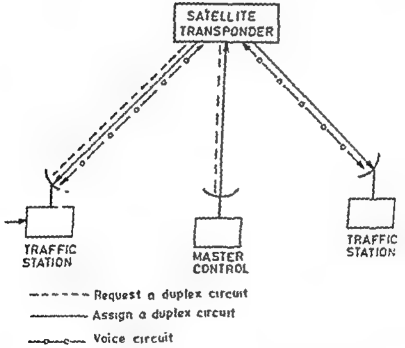

Fig. 6.2. Centralized Control Demand Assignment

[illegible] stations. Then it assigns a pair of channels and allows the two stations to [illegible] other through the satellite. When the call is completed, the master

control station releases the duplex circuit and returns the pair of channels to the satellite pool or station pool so that these may be utilized to a new caller on demand. Thus the master control station keeps track of actual satellite channel occupancy or channel availability at all the stations in the network. The distributed control demand assignment does not use any master control station. Each traffic station has a data base of the status of the channels and selects the available channel according to its need.

Both the centralized and [illegible]
assignments have [illegible]
of centralized co[illegible]
perform the func[illegible]
Since it maintai[illegible]
capacity of each s[illegible] according to traffic intensity and collect statistical data for traffic analysis and call logging data for off-line billing. Further, it requires less overheads as control data can be compact and status data for the whole network need not be transmitted. The disadvantages of centralized assignment is that the whole communication network relies on the central controller and so any outage at the master control station would [illegible]
Thus the reliability is po[illegible]
Furthermore, it needs a [illegible]
stations to the master co[illegible] station and also a *capacity assignment channel* is needed for the master control station to communicate with the traffic stations. These make the system less efficient for a high traffic demand assignment system.

The advantages of distributed control DAMA system is that it does not need any unique controller or so and therefore the reliability is good. Since the traffic stations make channel assignments by themselves via a *common signalling channel*, so, the failure of one station does not affect the [illegible]
The disadvantages are that ea[illegible]
channels and so the termina[illegible]
maintaining the network dat[illegible] itself is complex. Further the lack of coordination among stations may result in a poor use of [illegible]
mix of both [illegible]

[illegible] (SPADE) System

SPADE system is [illegible]
Intelsat IV [illegible]
channel pe[illegible]
from SCPC [illegible]
representin[illegible]
assignment [illegible]
use in [illegible]
with [illegible]
SCPC [illegible]
contr[illegible]
assign[illegible]
assign[illegible]

Fig. 6.3 shows the spade frequency plan at IF. With spade 800 PCM - encoded voice band channels separately QPSK modulate an IF carrier

minimum bandwidth 32 kHz. There is a 45 kHz bandwidth allocated to each channel. This allows for a 13 kHz guard band between each

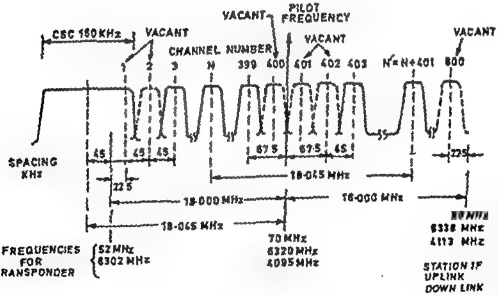

Fig. 6.3 Spade Frequency Plan

$$f_N = 0.045N + 51.9775 \text{ MHz} \qquad \ldots(6.3)$$

The center of the transponder band (70 MHz) is marked by a pilot carrier (pilot frequency) provided by the network's reference station. To avoid interference with the pilot, the channels immediately above and below it (401 and 400) are not used and these portions of the spectrum are unoccupied. In addition channels 1 and 2 are left vacant to accommodate the common signalling channel (CSC) that provides network control information.

The telephone conversation are carried by a pair of channels above and below the pilot. Thus a total of 397 such pairs are available and this is the number of simultaneous duplex channels that a 36 MHz transponder using SPADE can provide. The channel pair is automatically allocated to an incoming call by a DASS unit. Each SPADE terminal maintains a complete [illegible] DASS [illegible] circuit.

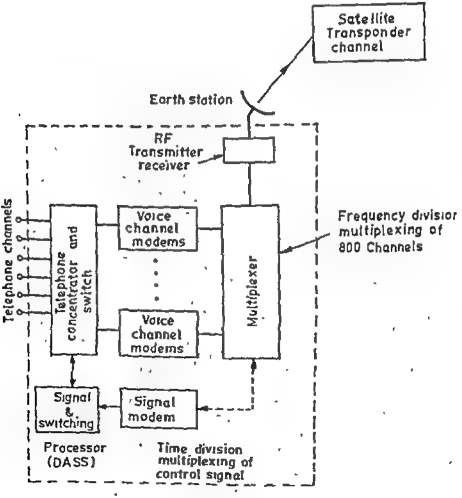

Fig. 6.4. Basic Block Diagram of SPADE Operation at an Earth Station

The common signalling channel (CSC) is of 160 kHz that each IF channel has. The CSC is a time division multiplex transmission that is frequency division multiplexed onto the IF spectrum below the QPSK - encoded voice band channels. The TDM frame structure for the CSC consists of total frame time of 50 ms which is subdivided into fifty 1 ms epochs. Each earth stations

discussed above. It is evident that SPADE has considerable capacity advantages over a 36 MHz bandwidth transponder using preassignment of carriers because there are 800 total voice channels available per transponder but the cost of ground equipment needed for signal processing is high.

6.5. Demand Assignment TDMA (DA-TDMA)

In the fixed assignment TDMA discussed in sections 5.2 and 5.3, the time frame has slots of fixed duration and the slots are permanently allocated to each of the stations. As already shown in Fig 6.1 there is always a chance of slots getting wasted during lightly loaded earth stations. The demand

(of Fig. 5.3) because of some additional channels for demand assignment.

Fig. 6.5 indicates a typical DA-TDMA frame structure. A superframe

at a station exceeds its allocated capacity in the frame, the station sends a *capacity request message* to the reference station asking for the additional capacity (a certain number of voice channels, for example) via the *capacity request channel*. The station continues to send this message once per

or once per superframe sequentially depending on the channel rate. The assignment message contains information on the burst length (in voice

channels, for example), burst position (in symbols, relative to the last symbol of the unique word of the primary reference burst), and possibly the transnponder. It should be noted that the frame reconfiguration is not

quickly search the frame to find available capacity and then assign it to the traffic stations that request it. It would be worthwhile to mention here that the traffic station before transmitting the acknowledgment of the capacity

etc. use TIMs for DA-TDMA purposes.

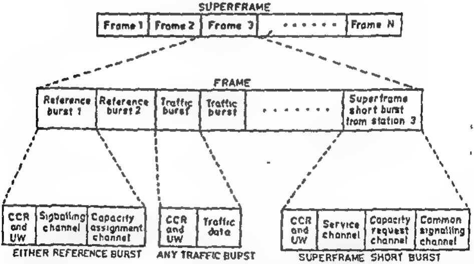

Fig. 6.5. DA-TDMA Frame Structure

6.6. Digital Speech Interpolation

Digital Speech Interpolation (DSI) is another efficient technique for increasing the satellite capacity. It does it by assigning the transmission

[illegible]

hardware for its implementation.

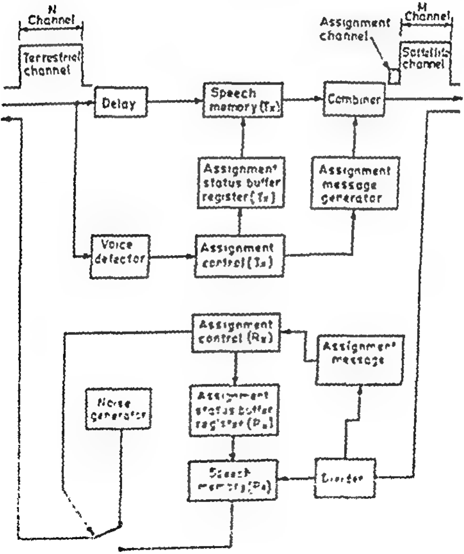

Fig. 4.6 Basic Block Diagram of DSI System

The basic block diagram of DSI system is shown in Fig. 6.6. The whole system is also called *digital speech interpolation interface*. In the transmit side the voice or speak detector detects whether speech signals are present or not on each of N incoming terrestrial channels and then the channels containing active speech signals are connected to M satellite channels for transmission to the receiving station. Thus the speech detectors sense speech energy and then seize a satellite channel. Whenever a speech detector senses energy on a terrestrial channels, the terrestrial channel is assigned to a satellite channel. The satellite channel assigned is randomly selected from the idle satellite channels. [illegible]

single call.

For demultiplexing purposes, the terrestrial channel/satellite channel assignment information is conveyed to the receive terminal. This is done through an assignment channel (a common signalling channel) similar to the one used on the SPADE system. Infact satellite channel assignments are transmitted by means of assignment messages (AMs) which consist of terrestrial channel number and an associated satellite channel number. In Fig. 6.6 the satellite channel [illegible] evident that Digital Speech Interpolation is a form of demand assignment because the satellite channels are randomly assigned on an as needed basis.

From above discussions on DSI, it is clear that the DSI has *channel compression*. In other words there can be more terrestrial channels than the satellite channels. Generally a terrestrial channel/satellite channel ratio of 2:1 is used. For a full duplex (2 way simultaneous) communication circuit, there is a speech in each direction 40% of the time and for 20% of the time the circuit is idle in both the directions. Therefore, a DSI gain slightly more than 2 is realized. In Intelsat 127 satellite [illegible]

[illegible] *phenomena* because in such a situation the incoming speech channel could not be assigned a satellite channel or is *frozen out*. Competitive clipping is not noticed by a subscriber if its duration is less than 50 ms.

In DSI [illegible] results in eight channels with 7 bit resolution for the time that the overload channel is in use.

6.7. Review Questions

1. Explain the difference between preassignment and demand assignment multiple access systems. Compare and contrast the relative advantages and disadvantages.

2. Explain the Erlang B formula. Show as to how can it be used to find out the improvement of DAMA over Preassignment Multiple Access for a given traffic.
3. [illegible] blocked.
   (Ans : $\lambda = 30$ calls per hour, p_0 (2 min) = 0.368, B (3,1) = 0.0625)
4. What is the function of Demand Assignment Control in DAMA systems? Explain various such control systems.
5. What is a common signalling channel and how is it used ?
6. What is SPADE ? Briefly decribe the operation of COMSAT'S spade system.
7. [illegible]
8. Explain the DA-TDMA burst structure. In what way is it different from a simple TDMA burst structure ?
9. What is digital speech interpolation ? Describe the working of a digital speech interpolated iterfaces ?
10. What is channel compression and how is it accomplished with a DSI system ?
11. Describe competitive clipping and bit stealing in DSI systems. In what way do these affect the DSI working ?

6.8. References

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SEVEN

Spread Spectrum Technique and Code Division Multiple Access

7.1. Introduction

The spread spectrum system is one in which the transmitted signal is *spread* over a wide frequency band, much wider, infact, than the minimum bandwidth required to transmit the information being sent. In other words a [illegible] technique. A typical example of a spread spectrum modulation is that of conventional frequency modulation in which deviation ratios greater than one are used. The rf spectrum product is much wider than the transmitted [illegible] the information.

Spread spectrum modulation techniques or spread spectrum multiple access techniques have several advantages as compared to conventional communication systems. A properly designed spread spectrum [illegible] special techniques to decode the transmitted messages. With these advantages, spread spectrum techniques are widely used in defense communication systems.

There are 3 kinds of modulation techniques normally being used in spread spectrum techniques The first one is the *direct sequence modulation* (DS)

technique in which modulation of a carrier is being done by a digital code seqeunce whose bit rate is much higher than the information signal bandwidth. The second technique is *frequency hopping* (FH) in which the carrier frequency shifting is done in discrete increments in a pattern dictated by a code sequence. Here the transmitter jumps from frequency to frequency within same predetermined set; the order of frequency usage is determined by a code sequence. In the third technique known as *chirp modulation* or *pulsed FM modulation* carrier is swept over a wide band during a given pulse interval. It may be noted that similar to frequency hopping there are *time hopping* and *time frequency hopping* where time of transmission (usually of low duty cycle and short duration) is

... has not robust at all and so it did not become popular.

7.2. Process Gain and Jam Margin

The properties of spread spectrum communication systems are characterized by two important parameters, namely the *process gain* and *jamming margin*. The process gain is defined as the difference between the output and input signal to noise ratios. For example in the frequency modulation case it is called fm improvement and is equal to 10 log $(3/2)m^2$ (Discussed in section 3.4) where m is the fm modulation index given by $m = \Delta\omega / \omega_m$, $\Delta\omega$ being the frequency deviation. Thus for a given processor

... namely

$$\text{process gain}, G_p = \frac{BW_{rf}}{R_{inf}} \qquad \ldots(7.1)$$

where BW_{rf} is the ...

The importance of ...

... the noise (or interference) exceeds some threshold value (typically around 10 db). The received signal power is the product of the energy per bit and the bit rate. Thus

$$P_r = E_b\,(\text{Joules / bit})\; R\;(\text{bit / second}) \qquad \ldots(7.2)$$

Interference power from the other spread spectrum users is the product of their combined interference spectral density N_0, and the receiver input bandwidth B(or W_{ss})

$$P_i\,(\text{watts}) = N_0(\text{watts / Hz})\,.\,W_{ss}\,(\text{Hz}) \qquad \ldots(7.3)$$

Thus at the input of the receiver, the signal to interference power ratio is

$$\mathrm{SIR}=\frac{P_r}{P_I}=\frac{E_b}{N_0}\cdot\frac{R}{W_{ss}} \qquad ...(7.4)$$

interferences present, in the same band at the same time, and the receiver could still operate with the required performance level.

Jamming margin expresses the capability of a system to perform in interfering (hostile) environments. Jamming margin takes into account the requirement for a useful system output signal to noise ratio (minimum $(S/N)_{out}$ of the system) and allows for internal losses. Thus the jamming margin is evaluated by the formula

$$M_j=\text{jamming margin}=G_p-[L_{sys}+(S/N)_{min\ out}] \qquad ...(7.5)$$

to noise ratio improving techniques.

7.3. J/S Ratio and Antijam Margin

$$J_0=J/W_{ss} \qquad ...(7.6)$$

... received jammer power (jammer power referred to the

$$E_b = ST_b = S / R \quad ...(7.7)$$

where S is the received signal power, T_b is the bit duration, and R is the data rate expressed in bits/s. Then $(E_b/J_0)_{reqd}$ may be expressed as

$$(E_b / J_0)_{reqd} = \left(\frac{S / R}{J / W_{ss}}\right)_{reqd} = \frac{W_{ss} / R}{(J / S)_{reqd}} = \frac{G_p}{(J / S)_{reqd}} \quad ...(7.8)$$

where G_p is the process gain defined in Eq. (7.1.) Then Eq. (7.8) gives

$$(J / S)_{reqd} = \frac{G_p}{(E_b/J_0)_{reqd}} \quad ..(7.9)$$

The ratio (J/S) ... how ... is the ... capability but it forces the communicator to employ a greater processing gain.

Antijam margin means the safety margin against a particular threat (Jamming). It is represented by M_{AJ} and is given by

$$M_{AJ}(dB) = \left(\frac{E_b}{J_0}\right)_r dB - \left(\frac{E_b}{J_0}\right)_{reqd} dB \quad ...(7.10)$$

where $(E_b/J_0)_r$ is the E_b/J_0 *actually* received. Now, $(E_b/J_0)_r$ may be expressed as

$$\left(\frac{E_b}{J_0}\right)_r = \frac{G_p}{(J / s)_r} \quad ...(7.11)$$

$$M_{AJ}(dB) = \frac{G_p}{(J / S)_r} dB - \frac{G_p}{(J / S)_{reqd}} dB$$

$$= (J / S)_{reqd} dB - (J / S)_r dB \quad ...(7.12)$$

It may be noted that quite often ... margin since it ...

7.4. Direct Sequence Spread Spectrum Techniques

In the direct sequence modulation the amplitude of ... signal is amplitude modulated b... In other words in the direct se... modulated with ...

$$s(t) = \sqrt{2p_s}\, d(t) \operatorname{Cos} \omega_0 t \quad ...(7.13)$$

(which is actually a binary PSK signal), the DS spread spectrum signal obtained by constant envelope modulation of wave (7.13) by the spreading signal $g(t)$, is expressed as

$$v(t) = g(t)\,s(t)$$

$$= \sqrt{2ps}\,g(t)\,d(t)\cos\omega_0 t \qquad \ldots(7.14)$$

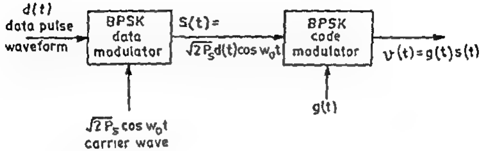

Fig. 7.1. Basic Block Diagram of a Simple DS Spread Spectrum Modulation

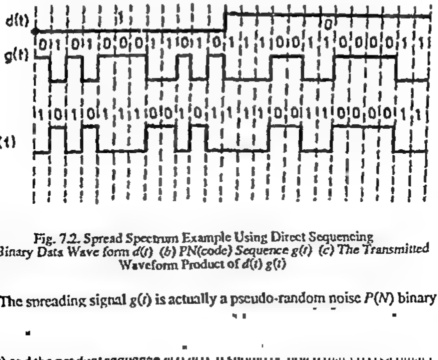

Fig. 7.2. Spread Spectrum Example Using Direct Sequencing
(a) Binary Data Wave form $d(t)$ (b) PN(code) Sequence $g(t)$ (c) The Transmitted Waveform Product of $d(t)\,g(t)$

The spreading signal $g(t)$ is actually a pseudo-random noise $P(N)$ binary

of $g(t)$ and the product sequence $g(t)\,d(t)$. It should be noted that $g(t)$ is a binary sequence as is the data $d(t)$. The sequence of $g(t)$ is generated in a deterministic

manner and is repetitive. But without serious error it can be assumed as truly random *i.e.* there is no correlation between the value of a particular bit and the value of any other bits. The details of *PN* sequence are given in the next section.

[illegible]

whereas f_c is called chip rate, f_b would be simply the bit rate. The product sequence $d(t)\ g(t)$ in Fig. 7.2.(c) is similar to $g(t)$ and if $g(t)$ is truly random, the product sequence would be another sequence $g(t)$ having same chip rate f_c as $g(t)$. Now, the bandwidth of the BPSK signal $s(t)$ is nominally $2f_b$ and similarly the bandwidth of PBPSK spread spectrum signal $v(t)$ is $2f_c$. It can be easily said that the spectrum has been spread by the ratio f_c/f_b. Since the power transmitted by $s(t)$ and $v(t)$ is the same, *i.e.*, P_s, the power spectral density $G_s(f)$ is reduced by the factor f_c/f_b. The ratio f_c/f_b is the process gain G_p *i.e.*,

$$G_p = f_c / f_b \qquad ...(7.15)$$

[illegible]

accomplished with conventional demodulator. Actually, in the receiver side, the incoming DS SS signal is first multiplied with the waveform $g(t)$ and the carrier $\sqrt{2}\cos\omega_0 t$. This requires the regeneration of both the carrier and *PN* sequences $g(t)$ at the receiver side.

The DS spread spectrum technique [illegible]

normalized power P_j then the quantity P_{jeff} given by

$$P_{jeff} = \frac{P_j}{2(f_c/f_b)} \qquad .(7.16)$$

represents the effective jamming power.

7.5. PN Sequences

As already mentioned the spreading signals used in the spread spectrum technique are the pseudo-random or pseudo-noise sequences. These are noise like but deterministic [illegible]

sequence has a very important role to play in the spread spectrum system because it directly affects the [illegible]

The bandspreading codes (*PN* sequences) used are the maximal length codes. These are therefore oftenly called *m*-sequences. Infact these are the longest codes that can be generated by a given shift register or a delay element

its input. The output of a sequence generator and the contents of its *n* states at any sample (clock) time is a function of the outputs of the states fed back at

The *PN* sequences have certain other properties as described below. The

linearly from the -1 value to $2^n - 1$ (the sequence length). A 1023 bit maximal code ($2^{10} - 1$) therefore has a peak to average autocorrelation value of 1024, a range of 30.1 dB. The *m* sequence autocorrelation function is as that shown in Fig. 7.3.

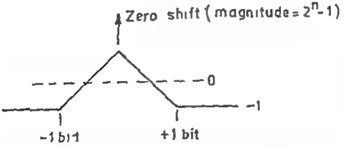

Fig. 7.3. *m* Sequence Auto Correlation Function

PN sequences follow the modulo 2 addition principle. A modulo-2

$$\begin{Bmatrix} 0 \oplus 1 = 1 \\ 0 \oplus 0 = 0 \\ 1 \oplus 1 = 0 \end{Bmatrix} \quad \ldots(7.17)$$

It would be worthwhile to mention here that various maximal length codes may be combined to give the so called composite codes which have also been used in spread spectrum communication systems. These composite codes are of several types such as JPL ranging codes, the Gold codes etc. These codes have better correlation properties.

7.6. DS CDMA

The spread spectrum technique has direct application in satellite communication system through code division multiple access where multiple signals occupying the same rf bandwidth are to be transmitted simultaneously without interfering with one another. The CDMA was already introduced in Section 5.12. If a single DS spread spectrum is used, it may provide protection against interference but the bandwidth is greatly wasted. To improve the bits-per-hertz throughput the advantage is taken of the low peak cross-correlation value in a set of DS addressed codes such as Gold sequences. Thus in a direct sequence CDMA satellite system, each uplink earth station has its own addressed *PN* sequence and unlike the situation in TDMA and FDMA where the carriers are separated by time or frequency, all active stations transmit their carriers on the same allocated bandwidth and overlap in time Fig. 7.4. Indicates the Principle of DS-CDMA System transmission. Here the output of several DS-spread spectrum modulators, say N are using their own codes $g_i(t)$ where $i = 1, 2 ... N$. After combining these together these are transmitted. The user codes are approximately orthogonal so that the cross-correlation of two different codes is near zero. It should be noted that each of the users is transmitting data at the same carrier frequency and each pseudo-random frequency $g_i(t)$ has the same chip rate f_c. The data rate for each user is also the same f_b. Thus the signal after transmitted back by the satellite to the receiver would be a combination of $g_1(t)\,s_1(t) + g_2(t)\,s_2(t) + ...\, g_N(t)\,s_N(t)$ ...(7.18)

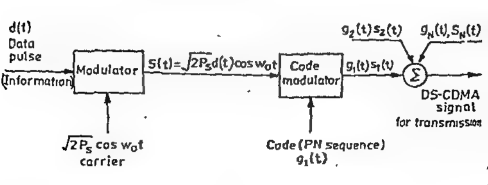

Fig. 7.4. Principle of DS-CDMA Technique

At the receiver side arrangements are being made to receive the message from desired user group. Here the corresponding $g_i(t)$ is generated at the receiver and is perfectly synchronized with the received signal from the corresponding with user. The first step in the receiving process is to multiply the incoming

Desired signal : $g_1^2(t)\, s_1(t)$
plus a composite of undesired signals

$$g_1(t)\, g_2(t)\, s_2(t) + g_1(t)\, g_3(t)\, s_3(t) + \ldots + g_1(t)\, g_N(t)\, s_N(t) \qquad \ldots(7.19)$$

If the code functions $\{g_i(t)\}$ are chosen with orthogonal properties, the desired signal can be extracted perfectly in the absence of noise since $\int_0^T g_i^2(t) = 1$ and the undesired signals are easily rejected since $\int_0^T g_i(t)\, g_j(t)\, dt = 0$ for $i \neq j$. The basic block diagram of a typical DS spread spectrum receiver (decoder) is shown in Fig. 7.5.

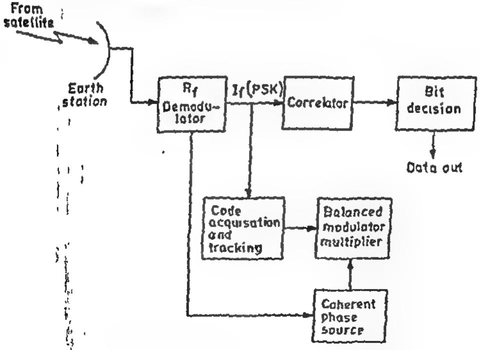

Fig. 7.5. Basic Block Diagram of a Typical DS-SS Receiver

As shown in Fig. 7.5 the incoming RF signal is first down converted to IF and then the $g_1(t)$ is multiplied to this IF signal and then the product is compared with the received IF signal in the *correlator*. The function of the correlator is to compare the two signals and recover the original data. Essentially the correlator subtracts the recovered PSK carrier + chip code from the received PSK carrier + chip code + data. The resultant is data. In fact the output of correlator which is the desired signal occupies the information bandwidth centered at an intermediate frequency (IF). It is applied to a [illegible]

[illegible]

and matched filters etc.

7.7. Frequency-Hopping Spread Spectrum Communication System (FH-SS)

The main difference between frequency hopping SS system and a DS SS system is that in frequency hopping the total available bandwidth is partioned into smaller frequency bands and the total transmission time is subdivided into smaller time slots. Thus transmission takes place within a limited frequency band for only a short period of time, then switches to another frequency band [illegible]

[illegible]

[illegible] *multiple frequency, code-selected, frequency shift keying*. The code pattern generator consists of *PN* code generator and a frequency synthesizer capable of responding to the coded outputs from the code generator. [illegible]

$$s(t) = \sqrt{2P_s}\cos(\omega_c t + \dot{d}(t)\,\Omega(t) + \theta) \qquad \ldots(7.20)$$

where $d(t)$ is the data to be transmitted. After FHSS modulation the resulting frequency hopped signal can be expressed as

$$s(t) = \sqrt{2P_s}\cos(\omega_i t + d(t)\Omega(t) + \theta) \qquad ...(7.21)$$

where $f_i = \omega_i / 2\pi$, is the carrier frequency of FH signal which changes at the hopping rate R_h. In other words the carrier frequency f_i changes at each $1/R_h = T_h$ seconds. The frequency is constant on such time intervals T_h. This parameter T_h is called the *frequency dwell time* or *hop interval*. The frequency chosen at each T_h is selected in a pseudo-random manner from a specified set of frequencies.

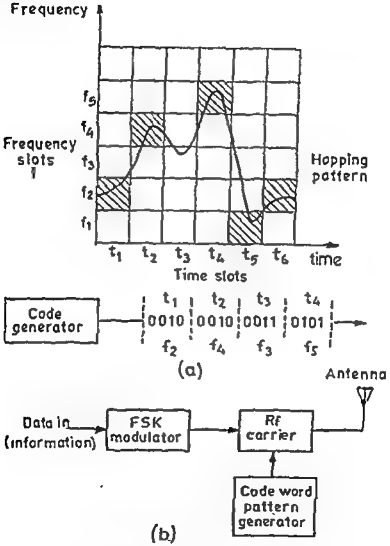

Fig. 7.6. FH System (*a*) Frequency Time Hopping Matrix (*b*) Frequency Hopping Transmitter

[illegible]

$$G_p = \text{the number of available frequency choices}$$

$$= N \quad \ldots(7.22)$$

which also holds good for contiguous channels. Thus for a frequency hopping system containing 1000 frequency choices could have 30 dB available process gain. It may be mentioned that in above calculations for [illegible] interchannel [illegible]

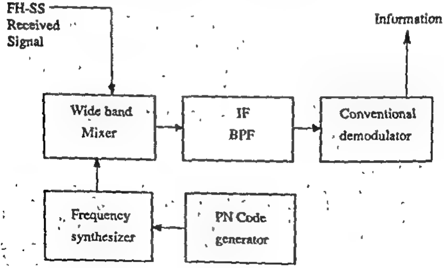

Fig. 7.7. Simple Block Diagram of FH SS Receiver

FHSS system may be a fast FH SS system or a slow FHSS system. In fast

much on the data rate.

7.8. Frequency Hop Spread Spectrum Code Division Multiple Access (FH-SS CDMA)

FHSS technique is also used in multiple access system in the way similar to that of DSSS-CDMA. With frequency hopping, each earth station within a CDMA network is assigned a different frequency hopping pattern. Each

DS-CDMA in many military applications. On the other hand DS-CDMA may be more suitable for commercial users.

It would be of interest to compare CDMA with FDMA or TDMA irrespective of the fact that CDMA is suitable for security reasons or interference rejection. Theoretically all the multiple access systems may support the same numbers of users in a given bandwidth. Differences in capacity between them arise from practical considerations like

attractiveness for multiple access.

7.9. Synchronization

orrelators.

The acquisition or initial synchronization process may be either as coherent or noncoherent. ...

... method is a typical example of serial search method. Sometimes special codes like those of JPL codes are used for initial synchronization.

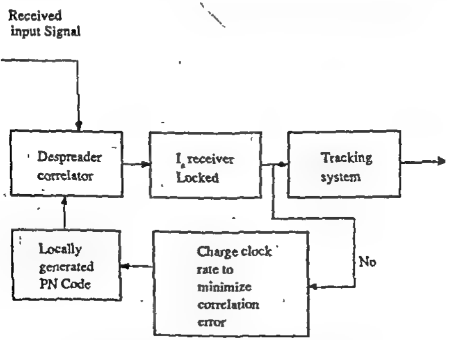

Fig. 7.8. Basic Principle of a Simple Slide Correlator Synchronizer

The principle of parallel DS search technique ... the local ... half chi... the rece... uncertai... are used ... simultaneously examines a ...

which the $2N_c$ correlator outputs are compared. The locally generated corresponding to the correlator with the largest output is chosen. It must be noted that λ is chosen as a compromise between minimizing the probability of a synchronization error and minimizing the time to acquire.

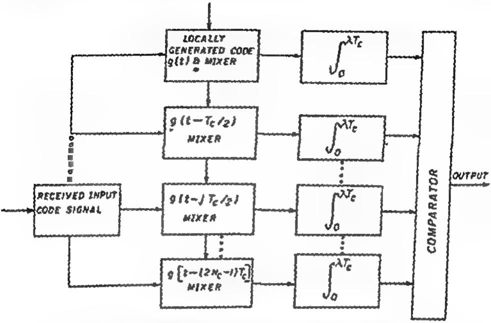

Fig. 7.9. Principle of Parallel DS-SS Search System

The FH initial synchronization system may also employ both parallel and [illegible]

search is

$$(T_{acq})_{max} = \lambda T_c \qquad \text{...(7.23)}$$

If P_D is the probability of detection for such correlated outputs, then in case some incorrect outputs appear, the further acquisition time to examine additional λ chips is

$$T_{acq} = \lambda T_c P_D + 2\lambda T_c P_D (1-P_D) + 3\lambda T_c P_D (1-P_D)^2 + \ldots$$

$$= \frac{\lambda T_c}{P_D} \qquad \ldots(7.24)$$

It must be remembered that parallel acquisition system requires severa' correlators or matched filters and so serial acquisition system is more economical and simple. In Fig. 7.8 which is essentially a serial acquisition system for DS-SS, a frequency hopper will be needed alongwith the *PN* code generator for FH systems. It would be of importance to mention here that recently another search technique called *Rapid Acquisition By Sequential Estimation* (RASE) has also been proposed for the initial synchronization which works in sequences and has a rapid acquisition capability. The RASE system has the disadvantages of being highly vulnerable to noise and interference signals.

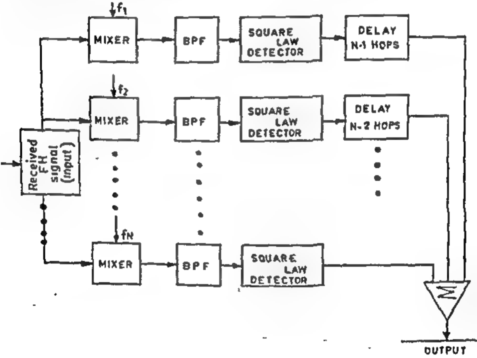

Fig. 7.10. Basic Block Diagram for the Parallel Search Acquisition for FH SS System

After initial acquisition has been achieved, the system takes to tracking or fine synchronization. As already mentioned the tracking systems are basically the ... *loop* (TDL). ... shared early ... frequency and phase of the received signal are not known exactly noncoherent tracking loops are used. Fig. 7.11 indicates the principle of

working of Delay locked loop for tracking the direct sequence spread spectrum signals. It is assumed that DS-SS signal is BPSK modulated and at the receiver input has the form (similar to that in Eq. 7.14)

$$u(t) = A\sqrt{2P_s}\, s(t) g(t) \cos(\omega_0 t + \phi) \qquad \ldots(7.25)$$

where A is a constant and represents system gain parameter, ϕ is a random phase angle in the range $(0, 2\pi)$. The local *PN* code generator is adjusted such that the locally generated *PN* code is offset in phase from the incoming $g(t)$ by a time τ where $\tau < T_c/2$. The loop provides fine synchronization by first generating two *PN* sequences $g(t + T_c/2 + \tau)$ and $g(t - T_c/2 + \tau)$ delayed from each other by one chip. DLL has also two band pass filters (BPF) which pass the data and help in averaging the product of $g(t)$ and two *PN* sequences $g(t \pm T_c/2 + \tau)$. Since $|s(t)| = 1$ so the two square law envelope detectors eliminate the date. The output ofeach envelope detector can be approximated as

$$E_D = E\left\{\left|g(t)\, g\left(t \pm \frac{T_c}{2} + \tau\right)\right|\right\} \qquad \ldots(7.26)$$

$$= \left|R_g\left(\tau \pm \frac{T_c}{2}\right)\right|$$

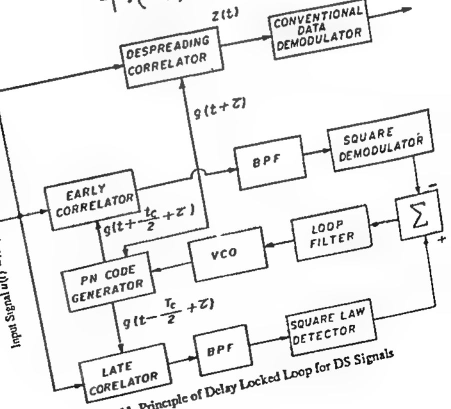

Fig. 7.11. Principle of Delay Locked Loop for DS Signals

Here E {.} means the *expected value* and $R_s(s)$ is the autocorrelation function of the *PN* waveform. Thus a resultant feedback signal $Y(z)$ is generated as shown in Fig. 7.11. When τ is positive the feedback signal $Y(\tau)$ instructs the voltage controlled oscillator (VCO) to increase its frequency. This would cause a decrease in τ. Similarly when τ is negative, $Y(\tau)$ instructs VCO to decrease its frequency. Then τ will be increased. Ultimately for very small values of τ, relation $g(t)\, g(t+\tau) = 1$ will be satisfied and the despreading

otherwise the offset signal $Y(\tau)$ will be offset and will not produce a zero signal when the error is zero.

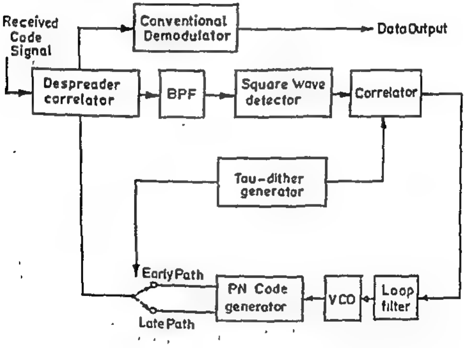

Fig. 7.12. Principle of TDL

identical transfer functions of the early and late paths. There is correlator needed to provide code tracking function and the function. Similar to that in DLL, here the received signal is

encrypted message is processed ...
syst
Wh
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effic ... system. In particular it provides the data security to the commercial satellite and antijamming capability to the military satellites.

7.12. Review Questions

1. What is meant by spread spectrum ? How can it be used for communication purpose ?
2. Explain the advantages and disadvantages of spread spectrum techniques.
3. What is meant by process gain, jam margin, *J/S* ratio and antijam margin ? Explain the importance of these parameters in spread spectrum communication systems ?
4. Explain the direct sequence and frequency hopping technieques of spread spectrum communication system. Compare the relative advantages and disadvantages.
5. In a spread spectrum satellite communication system the transmitted $EIRP_T$ is 20 dBW. The data rate is R = 100 bit/s. A jammer is transmitting wideband guassian noise continually with an $EIRP_J$ = 60 dBW. Assume $(E_b/J_0)_{reqd}$ = 10 dB. If the antijam margin is of 20 dB what should be the value of spread spectrum bandwidht *WSS*.

   (Ans : W_{ss} = 1 GHz)
6. What is *PN* sequence ? Discuss its characteristics. What is chip ?
7. What is CDMA ? How does it employ spread spectrum technique during the multiple access of the signals. Also explain the relative merits and demerits of CDMA, FDMA and TDMA.
8. Why is ...
9. What is a hybrid CDMA ...
   CI
10. Ex

7.13. References

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early and late version of the locally generated *PN* code. It may be noted that the signal to noise performance of the TDL is only about 1.1 dB worse than that of the DLL if the arm filters are designed properly.

7.10. Applications of Spread Spectrum Techniques

Spread spectrum techniques and CDMA systems can not compete with the potential capacity of FDMA and TDMA systems but there are applications in which practical operating constraints render the latter two systems highly inefficient and CDMA gains an edge because of its ability to handle low rate, bursty data more efficiently. Further if a satellite system is required to combat fading, multipath interference, jamming and noise, its multiple access capability will have to be sacrificed at least in part and for that CDMA is the only solution. It must be remembered that a satellite system using spread spectrum system operating at or near full multiple-access capacity will be roughly as visible and vulnerable to hostile action, as any other form of transmission.

[illegible]

technique is used for communications, ranging, multiple accessing and jamming protection. The systems used are both the direct sequence and frequency hopping. Primary user of these applications are for military purposes. Similarly the avionics system may employ spread spectrum technique for communications, position location, discrete addressing, low [illegible] these applications are again military.

The test systems and equipment area have the primary user commercial personnels. These are used for bit error detection, non-interfering-in service testing, signal correlation, privacy (pseudo) random selection and number [illegible]

techniques have undesirable problems.

7.11. Hybrid Systems

[illegible]

a band of spread spectrum demodulators where the exact replica of is stored to make the inverse operation to extract the message. The

encrypted message is processed ...
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effic ... system. In particular it provides the data security to the commercial satellite and antijamming capability to the military satellites.

7.12. Review Questions

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   (Ans : $W_{ss} = 1$ GHz)
6. What is PN sequence ? Discuss its characteristics. What is chip ?
7. Wh
8. Why is symbol
9. What is a hybrid CDMA
   CD
10. Ex

7.13. References

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EIGHT

Random Access Technique and Packet Satellite Communication

8.1. Introduction

The satellite demand assignments discussed in Ch...
one because the assignec...
with each other. A typical...
are *circuit oriented syste*...
they were designed to ser...
to the time *required to ma*...
for bursty data *traffic*, h...
improve channel efficiency over the case of fixed assignment. Packet communication systems utilizing random multiple access techniques were designed to provide *satellite* capacity demand assignment for bursty traffics.

In packet *satellite* communication packets of data are involved and the corresponding *systems may* be also packet radio or packet broadcasting systems too. The satellite system using packet ...

... systems at the University o...

Satellite channel used ... random access. In other wo...

... as necessary at random and some bursts overlap. Random access *is notably inefficient* ... occur ... also be ... *access* ... channe ... region

8.2. Packet Switching

Packet switching involves dividing the data messages into small bursts of information and transmitting them through communication networks to their intended destinations using computer-controlled switches. The overall concept

switching. *Hybrid switching* may also be employed.

Circuit switching (CS) is analogous to the telephone (voice) network.

is a transparent switch, the message switch is a transactional switch. Message

necessarily arrive at the receive end at the same time or in the same order in which they were transmitted. These give the packet switching additional

, packet switching networks require complex and expensive

switching arrangements and complicated protocols. While selecting circuit switching or packet switching in use a number of factors are to be considered.

than CS.

a transport scheme selection. Here the positive features of both the packet and circuit switching are combined eliminating the disadvantages of each. The main advantages of hybrid switching are such as low overhead in short packet

architectures are more complex than for simple packet or circuit systems. However, recent technological development like VLSI has reduced this problem to a great extent.

8.3. Packet Communication

In this section the definitions of various terminologies being used in packet switching, random access techniques and packet satellite networks would be explained.

Packet. A *packet* of information is a finite sequence of bits, divided into a control portion and a data portion. The common structure of a packet is shown

part of the packet consists of the source and destination codes, the packet number or termination code and the message priority information.

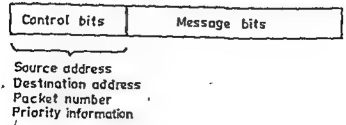


Fig. 8.1. Structure of Data Packet

ratio of successful packets to the total that were sent.

Packet Delay. The delay of a packet is simply the time between start and successful completion of transmission and delivery of the user. However, there are many detailed definitions of the delay and so comparisons may be difficult for different users.

Host. Host is the generic name in computer communications for the collection of hardware and software that uses the packet switching services to support user services.

provides network services through a host.

Routing. It defines a set of rules to determine the path over which message should flow from one side to anothers. There are several categories of routing strategies in computer communication networks.

Protocols. A protocol is a set of communication conventions, including formats and procedures, which allow two or more end points to communicate. In general, the end point may be packet switches, hosts, terminals, data bases, people and so on.

Virtual Circuit Call. Datagram and virtual circuit call are the two basic

datagram mode of operation is more economical.

8.4. Random Access Technique

The random multiple access scheme works on four different steps, namely

said to have *collided* and the users receive a negative acknowledgement (NAK). After having received NAK, the third step of random access technique is followed which is actually the retransmission of collided packets. In order that these retransmitted packets may not collide again, the interval of packet retransmision is randomized in each terminal. In other words now the users retransmit after a *random delay*. In case if after a transmission the user does not receive either an ACK or NAK within a specified time, the user retransmits the message. This is the final step of random multiple access and is termed time out.

The analysis of ALOHA system involves message arrival statistics. Suppose that in the satellite system the rate of successful arrival of packets is λ per second. Since there would be some packets lost due to collision so if λ_r is the rate of such lost packets per second, then the total traffic arrival rate λ_t would be

$$\lambda_t = \lambda + \lambda_r \qquad \text{...(8.1)}$$

Let the length of each message or packet be b bits. Then the throughput of the system which is actually the average amount of successful traffic would be expressed as

$$\rho' = b\,\lambda \text{ bits per second} \qquad \text{...(8.2)}$$

Similarly the total traffic G' on the satellite channel would be

$$G' = b\,\lambda_t \text{ bits per second} \qquad \text{...(8.3)}$$

If R bits per second represents the channel capacity (maximum bit rate) then the *normalized throughput P* and the *Normalized total traffic G* could be expressed as

$$\rho = \frac{b\,\lambda}{R} \qquad \text{...(8.4)}$$

$$G = \frac{b\,\lambda_t}{R} \qquad \text{...(8.5)}$$

Let the transmission time of each packet be τ given as

$$\tau = b\,/\,R \text{ seconds / packet} \qquad \text{...(8.6)}$$

Thus Eqs.(8.4) and (8.5) may be rewritten as

$$\rho = \lambda\tau \qquad \text{...(8.7)}$$

$$G' = \lambda_t\tau \qquad \text{...(8.8)}$$

In order that there may not be any collision between individual packets, a space of 2τ seconds is needed between each packet. This is because of the fact that if another user began a message within the previous τ seconds, its tail will collide with the current message and similarly if another user begins a message within the next τ seconds, it will collide with the tail end of the current message. The traffic arrival to the satellite repeater may be considered as a Poisson process because in most of the communication systems modelled as

Queueing systems the arrival of traffic is best explained by a Poisson process. Thus the probability of having K new messages arrive during a time interval of τ seconds is represented by the Poisson distribution as

$$P(K) = \frac{(\lambda\tau)^K e^{-\lambda\tau}}{K!}, K \geq 0 \qquad ...(8.9)$$

where λ is the average message arrival rate. Since within time interval of 2τ seconds no message is transmitted, *i.e.* $K = 0$ and then

$$P(K=0) = P_s = \frac{(2\tau\lambda_t)^0 e^{-2\tau\lambda_t}}{0!}$$

$$= e^{-2\tau\lambda_t} \qquad ...(8.10)$$

This is the case of a successful packet transmission because then there would be no collisions among packets. Here again λ_t represents the total traffic arrival rate. The probability of successful transmission, P_s can also be represented in a simple way as

$$P_s = \frac{\lambda}{\lambda_t} \qquad ...(8.11)$$

where λ is the successful portion of the total traffic rate λ_t. Thus from Eqs. (8.10) and (8.11) one gets

$$\lambda = \lambda_t e^{-2\tau\lambda_t} \qquad ...(8.12)$$

Eqs. (8.12), (8.7) and (8.8) combined together would give

$$\rho = G e^{-2G} \qquad ...(8.13)$$

Eq. (8.13) gives the relationship between the normalized throughput ρ and the normalized total traffic G for the ALOHA system. A plot of this relationship labelled as 'Pure Aloha' is shown is Fig. 8.2. This may be considered as a graph showing the successful transmission versus total transmission. It is evident that as G increases ρ increases but beyond $G = 0.5$, ρ starts decreasing. The maximum value of ρ corresponding to this $G = 0.5$ is [illegible] ALOHA system only 18% of the [illegible] uch random [illegible] ıpacity gets [illegible]

To improve the usage of channel capacity of Pure ALOHA system, [illegible] slotted ALOHA (S-ALOHA) is being [illegible] It must be remembered that the messages can be started [illegible]

another. Thus with the reduction of collision window from 2 τ to τ, the relationship between the normalized throughput ρ to the normalized total traffic G Eq.(8.13) now becomes

$$\rho = G.e^{-G} \quad ...(8.14)$$

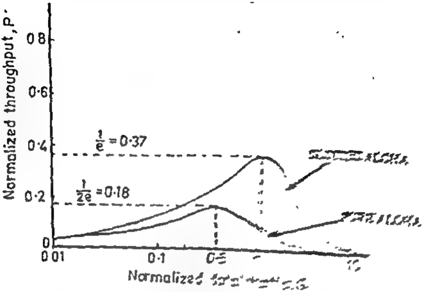
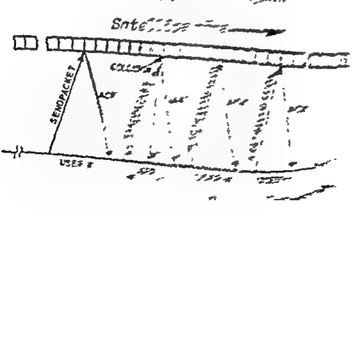


Fig. 8.2. Throughput



...ets they collide ... the users m and ... place, will be informed by the return of ACK. In case the packets m and n again collide, another retransmission of m and n packets would take place after another random delay. The process may repeat till the successful transmission takes ...

The slotted Aloha shows only 36% utilization of the satellite channel. To ...

The performance measure for multiple access schemes is usually carried out by the study of average delay versus normalized throughput. Fig. 8.4 indi-

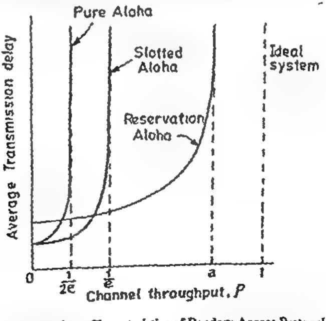


Fig. 8.4. Delay Throughput Characteristics of Random Access Protocols

cates the delay-throughput curve for random access multiple access techniques. For an ideal delay-throughput curve, the delay equals zero until the normalized throughput value $\rho = 1$ and then the delay increases without bound. Thus, it is apparent that R-Aloha is showing better performance than S-ALOHA. However, for values of ρ less than 0.2 the S-ALOHA manifests less average delay than R-ALOHA. But for values of ρ between 0.2 and a, R-ALOHA is superior since the average delay is less. Value a lies typically between 0.7 to 0.9. Thus at low traffic intensity S-ALOHA performs better. This is also due to the fact that S-ALOHA does not require the overhead slots as does the S-ALOHA. Therefore at low values of ρ, R-ALOHA pays the price of greater delay due to the greater overhead. For $\rho > 0.2$, the collisions and retransmissions inherent in the S-ALOHA system cause it to incur greater delay (unbounded at $\rho = 0.37$), more quickly than the R-ALOHA system. At higher throughput ($0.2 < \rho < a$) the overhead structure of R-ALOHA ensures that its delay degradation grows in a more orderly manner than S-ALOHA. For R-ALOHA the unbounded delay reaches at $\rho = a$.

In the explicit reservation scheme of the random access technique a network scheduler carries out a distinct and unique assignment of slots to a user. There are two such explicit reservation techniques, namely the R-TDMA and C-PODA (contention based Priority Oriented Demand Assignment). The R-TDMA protocol establishes a permanent association between slots and stations. The slots not claimed by the original owner may be reassigned on a 'round ribbon' basis to the stations that have traffic to send (round ribbon means that each station gets access in an ordered, sequential but not necessarily predetermined manner). Thus it is a dynamic reservation scheme. The C-PODA is a satellite channel access scheme which allocates slots to users based on prior reservation. The performance characteristics of the explicit reservation is similar to that of R-ALOHA shown in Fig. 8.4. However, R-TDMA shows lower delays than C-PODA.

8.5. Polling Techniques

Polling technique allows order (discipline) on multiple users of the packet oriented systems in random access technique. There is a central controller that periodically polls the user population to determine their service requests. Polling technique is efficient only if (*i*) round trip propagation delay is small, [illegible]

[illegible] search tree, techniques such as *adaptive polling* or *probing* are also used.

[illegible] to send their messages and are contending for the service on a single channel.

The tree search works on continually partioning the population until there is just a single branch remaining. Thus in the present example the satellite first requests for the transmission of contending terminals' first (left most) bit of their identification numbers (in Fig. 8.5 indicated by (*b*). Then the satellite on the basis of received signal strength selects one or zero. In the present example [illegible]

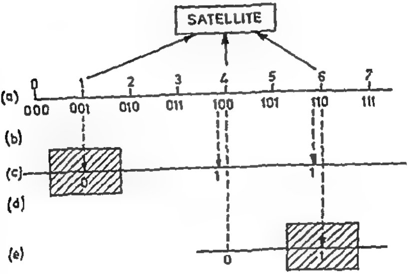


Fig. 8.5. A Typical Example of Tree Search Technique
[illegible] Satellite Requests Transmission of First [illegible] and notifies [illegible] (*e*) Satellite

The binary tree search technique described above requires $n = \log_2 Q$ decisions for each pass through a population of Q terminals. Infact a savings in time is possible by this technique only if population is large and the average [illegible] This advantage may be best understood by [illegible] 4096 [illegible] aight [illegible] 5s. In [illegible] sting [illegible] one [illegible] tree search is again Is then the time required by binary tree technique may also be calculated easily. Here the binary tree search for

100 terminals requires 100 passes through the binary tree and thus time required would be $(100 \times \log_2 4096) \times 1\ s = 1200\ s$. The maximum number of terminals being polled by the binary tree search technique in the time period equal to that required in straight polling is

$$Q' = \frac{Q}{\log_2 Q} \qquad \ldots(8.15)$$

For the example quoted above

$$Q' = \frac{4096}{\log_2 4096} = 341 \text{ terminals.}$$

Thus the maximum of terminals contending for service that a binary tree search may poll is 341 terminals.

8.6. Carrier Sense Multiple Access (CSMA)

In the C[illegible]
due to trans[illegible]
transmissior[illegible]
multiple access (CSMA) scheme each user tunes a receiver to the common [illegible]

[illegible]

delay say T_d, associated with a packet, then for the values of $T_d < 2T_p$ (T_p = received packet duration) CSMA is found to have significantly higher throughput than ALOHA and as a result CSMA has found numerous applications in computer communication field. The propagation delay of a packet arises due to the fact that when user transmits a packet it takes another user (d/c) seconds to receive the packet [illegible]

therefore $T_d = 2\,T_p = 200\ \mu s$ and the distance travelled $d = cT_d' = 3 \times 10^8$ ms $\times$ 2×10^{-4} s $= 60$ km. It is only due to this reason that CSMA [illegible]

[illegible]

are hidden from each other, either by distance or by terrain.

CSMA being used in Computer Communication [illegible]

[illegible]

probability that a ready packet persists. But in these techniques too there is some chance of packet collision [illegible]

[illegible]

users detect interference among several transmissions (including their own), they abort the transmission of colliding packets. This technique is now-a-days being widely used in *Local Area Computer Communication Networks*.

8.7. Queueing Systems

In packet communication, series of packets are being transmitted and individual packets move independently in the packet communication network. Hence there are queues formed by packets waiting for processing and transmission. Therefore queueing theory plays a major role in the analysis and design of packet networks. Queueing theory has vast applications in several areas ranging from day-to-day department store, airport and hospital queues to industrial queues such as inventories, assembly (or production) lines and [illegible] ve, wait in [illegible] indicates [illegible] messages [illegible] ng served. Servers serve the cust [illegible] the [illegible] me), number of [illegible]

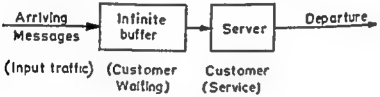


Fig. 8.6. Basic Block Diagram of a Simple Queueing System

There are a variety of queueing systems and their general classification scheme is given as

$$(x \mid y \mid z) : (u \mid v \mid \omega) \qquad \ldots(8.16)$$

where various symbols are as follows :

x – arrival (or interarrival) distribution
y – departure (or service-time) distribution
z – number of parallel service channels in the system
u – service discipline
v – maximum number allowed in the system (in service plus waiting)
w – size of population

Symbols x and y are commonly replaced by the following codes :

M – Poisson arrival or departure distributions (or equivalently exponential interarrival or service time distributions; M refers to the Markov property of the exponential distribution)

GI – general independent distribution of arrival (or interarrival times)

G – general distribution of departures (or service times)

D – deterministic interarrival or service times

The symbols Z, v and w are replaced by the appropriate numerical designations. The symbol u is replaced by a code similar to the following :

FCFS– first come first served

LCFS– last come first served

SIRO– service in random order

SPT– shortest processing (service) time

GD – general service discipline

In this [illegible] with an [illegible] disciplin[illegible] arrival [illegible] with the help of this ki[illegible] rmance of fixed assign[illegible]

Here the general service distribution means that the message length or service time has a randomly varying length and the single server works on one message at a time until completion. It is assumed that message arrival rate is equal to λ messages per unit time and the message consists of one or more packets, the length of message being an average length of $1/\mu$ time units. (μ being the average service rate). The average arrival rate multiplied by the $1/\mu$ service time is called the *traffic intensity* and represents the average load to the system

$$\rho = \frac{\lambda}{\mu} \qquad \text{...(8.17)}$$

The probability of the arrival of exactly K messages during an interval of length t is given by the Poisson law

$$P(K,t) = \frac{(\lambda t)^K e^{-\lambda t}}{K!}, \{t \geq 0, K = 0, 1, 2, \ldots\} \qquad \text{...(8.18)}$$

The expected value of K for a given interval t is

$$E\{K \mid t\} = \lambda t \qquad \text{...(8.19)}$$

The average number of messages waiting in the buffer including the one being served is given by the Pollaczek-Khinchine equation and is expressed as

$$E\{n\} = \rho + \frac{\rho^2 + \lambda^2 \sigma^2}{2(1-\rho)} \qquad \text{...(8.20)}$$

where σ^2 represents variance.

Eq. (8.20) is also called the *average M/G/1 queue length* or the *average buffer occupancy*. The average message delay which actually is the time elapsing between the arrival of a message at the buffer and the departure of the complete message is found by the *Little* equation, given by

$$T = \frac{E\{n\}}{\lambda}$$

$$= \frac{1}{\mu} + \frac{\lambda(1/\mu^2 + \sigma^2)}{2(1-\rho)} \qquad \text{...(8.21)}$$

The average time spent in a queue waiting to be served or the waiting or message is simply the average message delay less the average service time. This would be

$$W = T - \frac{1}{\mu} = \frac{\rho^2 + \lambda^2\sigma^2}{2\lambda(1-\rho)}$$

$$= \frac{\lambda(1/\mu^2 + \sigma^2)}{2(1-\rho)} \qquad \text{...(8.22)}$$

In case the service time is exponentially distributed, *i.e.* when $\sigma^2 = 1/\mu^2$,

$$T = \frac{1}{\mu(1-\rho)} = \frac{1}{\mu - \lambda} \qquad \text{...(8.23)}$$

Similarly when the service time is constant, *i e.* when $\sigma^2 = 0$,

$$T = \frac{2-\rho}{2\mu(1-\rho)} = \frac{2-\lambda/\mu}{2(\mu-\lambda)} \qquad \text{...(8.24)}$$

From Eqs. (8.23) and (8.24) it is seen that the message delay increases quickly as ρ approaches 1. The above relations now may be easily applied to a fixed assignment FDMA system. Suppose that the capacity of satellite

$$\mu = \frac{R}{Nb} \qquad \text{...(8.25)}$$

Now suppose μ be the average message arrival rate for each user. Then the traffic intensity for each channel would be

$$\rho = \frac{\lambda}{\mu} \qquad \text{...(8.26)}$$

Thus if the satellite roundtrip delay is T_- then the total message delay (T) for the FDMA channel would be

(i) for the case of an exponentially distributed message length :

$$T_{\mathrm{FDMA}}=\frac{1}{(R/Nb)(1-\rho)}+T_R \qquad ...(8.27)$$

(*ii*) for the case of a constant message length

$$T_{\mathrm{FDMA}}=\frac{2-\rho}{2(R/Nb)(1-\rho)}+T_R$$

$$=\frac{2-\lambda/(R/Nb)}{2(R/Nb-\lambda)}+T_R \qquad ...(8.28)$$

Fig. 8.7 plots the average message delay $T_{FDMA}-T_R$ versus traffic intensity ρ for a constant message length as functions of $N/bR = 1/\mu$. Here three values of $1/\mu$ namely 0.4s, 1s and 2s have been considered. The case of fixed assignment TDMA may also be considered in a similar queueing M/G/1 system and there the average message delay would be

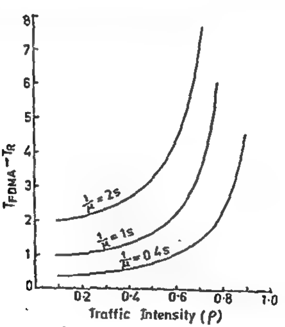


Fig. 8.7. Plot of T_{FDMA}-T_R as a Function of ρ.

$$T_{\mathrm{TDMA}}=T_{\mathrm{FDMA}}-\frac{T_f}{2}+\frac{T_f}{N} \qquad ...(8.29)$$

where T_f is the TDMA frame length and N is the number of the time slots in which the frame length T_f has been divided. Fig. 8.8 shows the plot of T_{TDMA}-T_R

$-T_R$ versus ρ. Once again here T_R is the satellite round trip delay. The plots of Fig. 8.8 are for three different values of frame length T_f, namely 2s, 1s and 0.4s. It is thus evident that in regards to message delay TDMA performs $\frac{T_f}{2}-\frac{T_f}{N}$ seconds better than FDMA. However, as mentioned earlier, both the fixed assigned FDMA and TDMA are not suitable for bursty traffics and there one uses the random multiple access system described in previous sections.

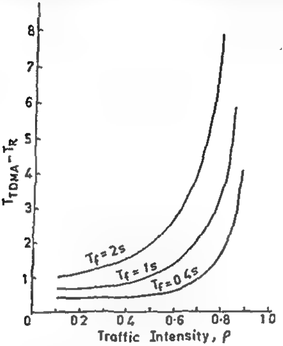


Fig. 8.8. Plot of T_{FDMA}-T_R Versus ρ.

8.8. Packet Satellite Networks

A variety of data formats and services may be provided by satellite networks. These may be such as telephony signals, TV (visual and audio) signals, computer generated signals (computer communication), broadcast

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PA

SATNET. It is Atlantic packet satellite network. Infact it was the most expensive field trial as of 1979 of packet satellite concepts, designs, developments and international cooperation.

WDPSN. It is wideband domestic packet satellite network. It uses SATNET technology in US Domestic *PSN*.

Data Retransmission. Here random access protocol is used and the satellite systems such as LANDSAT, NOAA/GOES etc use it.

GPSN. It is a general purpose packet satellite network.

Electronic Mail. Intelsat and some participant countries are operating Intelpost, an international system for electronic mail services.

SARSAT. It is Search and Rescue Satellite Aided Tracking System.

SOME Recently Developed Packet Networks

Computer communication networks like Telenet, Tymenet, Autonet, [illegible]

for various telematic services [illegible]

8.9. Review Questions

1. What are the various switching techniques and how packet switching is different from them ? Discuss various applications of packet switching.
2. What is meant by Random Multiple Access ? Compare its characteristics with those of FDMA and TDMA. Why is packet switching being used in random multiple access technique ?
3. What is queueing system ? How has it found applications in satellite communication system ? Discuss M/G/1 Queue system with regards to FDMA and TDMA satellite communication system.
4. In a satellite communication system using FDMA with 200 users and the [illegible] service rate of each FDMA channel and the average message delay for each user including a 270 ms satellite roundtrip delay.

   (Ans : 64 kbps, 6.4 messages per second, 495 ms)
5. What is ALOHA system ? Describe throughput and discuss the characteristics of Pure Aloha and Slotted Aloha in terms of throughput. What are the various techniques for improving throughputs ? Discuss a Reservation Aloha system.
6. What are Polling techniques ? Explain the polling technique used in binary tree search technique.

7. What is Carrier Sense Multiple Access Technique ? How is it different from ALOHA system ? Also discuss as to why CSMA is useful mainly to shorter distance communications in such as those of computer communication networks and not in satellite networks.
8. Assuming that Poisson process may be used for describing the packet transmissions and retransmission, calculate the probability that a data packet transmission in an S-Aloha system will experience a collision with one other user. Assume that the total traffic rate $\lambda_t = 10$ packets/s and the packet duration $\tau = 10$ ms

(Ans : 0.09).

8.10. References

Alongwith the references given in Chapter 7, following other references have also been used in preparing this section :

1. Agarwal, D.C., Computer Communication and ISDN systems, Khanna Publishers, Delhi, 1989.
2. White, J.A., Schmidt, J.W. and Bennett, G.K., Analysis of Queueing Systems, Academic Press, 1975.
3. Housley, T., Data Communications and Teleprocessing Systems, Prentice Hall, Inc, 1979.
4. Block, U., Computer Networks, Protocols, Standards & Interfaces, Prentice Hall, Inc, 1987.

NINE

Satellite Orbits and Inclination

9.1. Introduction.

The orbit of satellite in use for communication purposes has special significance. It is geostationary and has to be maintained geostationary at all [illegible] of geostationary orbit has already been discussed in chapter 1. Once the satellite is placed in geostationary orbit, it has to be parked in the desired slot till its whole life. Various kinds of manoeuvre are needed to do that. There are standard techniques to achieve them and all these are specified and recommended by the International Telecommunication Union (ITU) and Interna- [illegible] mation or traffic capacity. The communication satellite is a very large investment and its life is limited. It is therefore very essential that its full and proper utilization be made up the last end. In this chapter therefore the orbital aspects of the communication satellite are discussed.

It must be remembered that the communication satellites move around the earth as planets do around the sun and therefore the three Keplers' laws apply to them also. These kepler's laws are: (*i*) the orbit of satellite is an ellipse with the center of the earth at one focus, (*ii*) the line joining the center of earth and the satellite sweeps over equal areas in equal time intervals and (*iii*) the squares of the orbital periods of two satellites have the same ratio as the cubes of their mean distances from the center of the earth. The satellite orbit may be either elliptical or circular and its characteristics are governed by these laws. Infact these are the laws that initially developed the techniques for launching and putting the communication satellite in geostationary or any orbit (*e g.* low altitude satellites for special research purposes). The tracking of the satellite, its station keeping etc all depend on these Kepler's laws. The Newton's gravitational law of force also controls

the satellite's orbits and infact a very simple calculation regarding the geostationary satellite distance etc may be carried out from Newton's law of force.

The orbital aspects which are of importance are the determination of the orbit of the satellite, the distance between the satellite and earth stations, coverage angle, earth station pointing angles, eclipses and solar interference. The orbits may be far, near, equatorial, polar or inclined. The earth station antenna that communicates with the geostationary satellite requires a knowledge of azimuth angle and the elevtion angle with respect to latitude and longitude of the location of the earth station. A knowledge of the polarization angle is also necessary. The study of coverage areas requires the knowledge of the coverage angle and slant range. The duration of eclipse is essential to be calculated because during these periods the satellite has to depend on its own stored power as solar batteries remain idle then. The eclipse may be caused by the earth and the moon. The solar inteference appears in a variety of ways. It increases the antenna noise temperature when the sun is within the earth station beam. There is also a continuous drift in the satellite orbit both in longitude and latitude due to various disturbances. This drift is to be constantly nullified so that the orbit be stationary but perfect stationarity is not possible and so a satellite is constrained to remain within a 'window' whose limits are defined by an angular shift as seen from the center of the earth around the required nominal position. Usually this window is about 75 km on the sphere containing the geostationary satellite orbit.

9.2 Synchronous Orbit

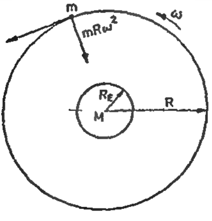


Fig. 9.1. Geostationary Orbit.

als the velocity of a point on the earth's equator. The geosynchronous altitude can be easity calculated. The movement of the satellite with respect to the earth can be considered as that shown in Fig. 9.1. Let M and m be the the mass of the earth and the satellite respectively. Similarly let R_g be the radius of synchronous circular orbit of the satellite. If ω is the angular velocity of the circular motion of the satellite in radians per second then the centripetal force acting on the satellite would be $mR\omega^2$. This centripetal force equal to the gravitational force (Newtons gravitational law) between the satellite and the earth expressed by GmM/R^2 where G is the gravitational constant. Thus

$$mR\omega^2 = \frac{GmM}{R^2} \qquad ...(9.1)$$

At the earth's surface the gravitational force is mg where g is the acceleration due to gravity. Then

$$\frac{GmM}{R_g^2} = mg \qquad ...(9.2)$$

From Eqs. (9.1) and (9.2) one can have

$$R = \left(\frac{gR_g^2}{\omega^2}\right)^{1/3} = \left(\frac{gR_g^2}{4\pi^2 f^2}\right)^{1/3} \qquad ...(9.3)$$

where $f = \omega/2\pi$ is the rotation rate in revolutions per second. Putting $f = 1$ revolution per day and $R_g = 6370$ Km, $g = 9.9$ m/s, one obtains $R = 42{,}208$ Km. Subtracting R_g form R one gets 35,838 Km as the orbital height above the equator which is quite close to the precise value of 35,860 Km. The maximum illumination of earth by a geosynchronous satellite is as that shown in Fig. 9.2. It is evident that polar regions are not illuminated by the

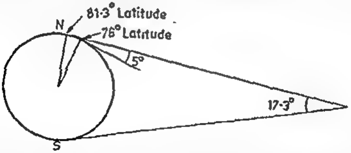


Fig. 9.2. Maximum Illumination of the Earth by a Geosynchronous Satellite

geosynchronous satellite. The angle subtended by the earth is 17.3° and the highest latitude at which satellite is visible is 81.3°. Further for all practical purposes an earth station requires a minumum elevation angle of atleast 5°

above the horizon. This reduces the highest latitude to about 76° at the longitude of the satellite. Corresponding to this 76° latitude of illumination the maximum distance illuminated by the geostationary satellite is about 16,900 Km which is around 42% of the equatorial distance. To cover the polar reqions therefore a satellite with an elliptical and inclined orbit is needed. A typical example is

are required to provide 24 hour coverage of the polar regions.

9.3. Orbital Parameters

The satellite's movement in an orbit follows the three Kepler's laws. The first Kepler's law gives that the satellite moves along a conic (orbit) on the orbit plane, the equation for which is

$$r = p/(1 + e\cos v) \qquad \ldots(9.4)$$

where p is a parameter, e is the eccentricity and v is the central angle (also called the true anomaly). *Fig. 9.3 represents the above orbit of satellite. Infact th'* value of the eccentricity e determines the type of the conic (orbit)

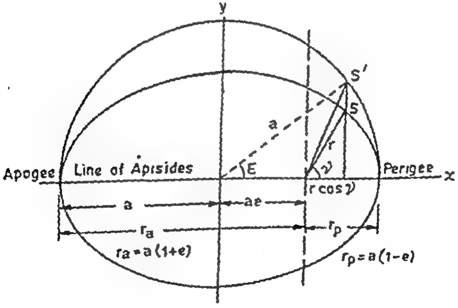


Fig 9.3. Geometry of an Elliptical Orbit of Communication Satellite.

$$e = \begin{Bmatrix} 0 \rightarrow circle \\ <1 \rightarrow ellipse \\ 1 \rightarrow parabola \\ >1 \rightarrow hyperbola \end{Bmatrix} \quad ...(9.5)$$

In Fig. 9.3 the elliptical orbit has been depicted. Here a is the semi-major axis and is linked to the orbital period by the expression

$$T = 2\pi \sqrt{\frac{a^3}{\mu}} \quad ...(9.6)$$

where μ is quantity equal to GM, G being the gravitational constant, equal to $6.672 \times 10^{-11}\ m^3\ Kg^{-1} s^{-2}$ and M being the earth's mass equal to5974×10^{24} Kg, thus $\mu = GM = 3.986 \times 10^{14}\ m^3/s^2$. *Satellite velocity* for a circular orbit is $\sqrt{\mu/a}$ where a is the orbit radius. Infact the satellite velocity at an orbital point s (distance to the centre of the earth r) is given by

$$V_s^2 = \frac{2\mu}{r} - \frac{\mu}{a} \quad ...(9.7)$$

It should be remembered that in Fig. 9.3 following definitions are made

$$x = r\cos\nu = a(\cos E - e) \quad ...(9.8)$$

$$y = r\sin\nu = a\sin E(1-e^2)^{1/2} \quad ...(9.9)$$

Ecentricity

$$e = c/a = \frac{(r_a - r_p)}{(r_a + r_p)} \quad ...(9.10)$$

Semi major axis

$$a = \frac{(r_a + r_p)}{2} \quad ...(9.11)$$

Apogee distance

$$r_a = a + c = a(1+e) \quad ...(9.12)$$

Perigee distance

$$r_p = a - c = a(1-e) \quad ...(9.13)$$

Locus parameter

$$p = a(1-e^2) = \frac{2r_a r_p}{(r_a + r_p)} \quad ...(9.14)$$

Semi minor axix

$$b = a(1-e^2)^{1/2}$$

$$= (r_a r_p)^{1/2} \quad \text{...(9.15)}$$

A synchronous satellite has T equal to the *sideral period* of rotation of its primary body, T_p (*i.e.* the period in any fixed reference coordinate system). It should be noted that for the earth T_p is not 24 hours (the so called synodal period) because in one day the earth both rotates once around its polar axis and also completes 1/36524 of the annual earth orbit around the sun. Consequently a geosynchronous satellite must have a period

$$T = T_p = \left(1 - \frac{1}{36524}\right) \times 24\ h$$

$$= 86163,44\ s$$

$$= 23^h\ 56^m\ 4^s \quad \text{...(9.16)}$$

in any fixed coordinate system. If

$$T = n\ T_p, n = 2,3,4, \quad \text{...(9.17)}$$

the satellite is called *super-synchronous* whereas a *sub-synchrounous* satellite has T and T_p interchanged in Eq. (9.17). In Eqs. (9.12) and (9.13), *perigee* is defined as a point in the orbit where the satellite is closest to the earth and similarly the point where the satellite is farthest from the earth is called the *apogee.*

As already mentioned before v is termed the *true anomaly* and is the positive angle oriented according to the velocity vector of the spacecraft, between the earth center to the satellite axis and the earth center to the perigee axis. Thus v specifies the position of the satellite on the orbit. Angle E is called the *ecentric anomaly* and is the central angle measured from the x axis to the vertical projection of the satellite point over the circle of radius a. The true anomaly v and the ecentric anomaly E are related by any of the expressions

$$\cos E = \frac{(e + \cos v)}{(1 + e \cos v)} \quad \text{...(9.18)}$$

$$\cos v = \frac{(e - \cos E)}{(e \cos E - 1)} \quad \text{...(9.19)}$$

$$\tan (v/2) = [(1+e)/(1-e)]^{1/2} \tan (E/2) \quad \text{...(9.20)}$$

Another kind of anomaly usully defined is M which is also called the *mean anomaly*. It may be considered as a true anomaly the satellite would have if it proceeded along a circular orbit of the same period T. This hypothetical circle may be considered as circumscribing the ellipse as shown in Fig. 9.3. Thus

$$m = \frac{2\pi t}{T} \qquad \ldots(9.21)$$

where $2\pi/T$ is the satellite mean motion. Angles M and E are related by the equation

$$M = E - e \sin E \qquad \ldots(9.22)$$

9.4. Satellite Location with Respect to the Earth

For an earth satellite, the reference frame is taken as rectangular coordinate system (OXYZ) with origin O in the earth's center of gravity. The z axis coincides with the polar axis and is oriented towards the north. The X-Y

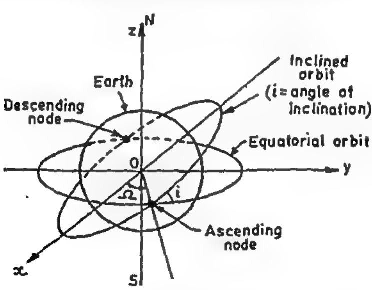


Fig. 9.4. Satellite Orbits

plane is thus the equatorial plane of the earth. [illegible]

[illegible]

the reference plane of the primary body ($i = 0°$). An orbit is *polar* if the orbit [illegible] 90°). An orbit is inclined [illegible] tes these equatorial and [illegible] rial orbits in which the satellite's projection on the equatorial plane of the primary body revolves in the same direction as the primary body itself are known as *direct orbits*. They

have inclinations less than 90°. Earth rotation is seen to assist the launching of satellites into direct orbits. Orbits for which $i > 90°$ are called *retrograde orbits*.

There are two points at which the orbit of the satellite penetrates the equatorial plane. These points are called nodes. There ae two such nodes, namely the *ascending node* and the *decending node* as shown in Fig. 9.4. THe satellite moves upward through the equatorial plane at the ascending node and downward through the equatorial plane at the descending node. It should be noted that in the reference frame OXYZ mentioned above the x axis (Fig. 9.4) points towards a fixed location in the free space called the *first point of Aries*. This is the direction of a line from the center of the earth through the center of the sun at the vernal equinox (about March 21), the instant when the subsolar point crosses the equator north to south. Angular distance measured eastward in the equatorial plane from the x axis is called the *right ascension* and is represented by the symbol *RA*. The right ascension of the ascending node is called Ω. Thus Ω is the longitude of the ascending node. Infact the variables Ω and i together locate the orbital plane with respect to the equatorial plane.

Another parameter of interest for the satellite orbit location with respect [illegible] parameter which may be either the true anomaly v or the mean anomaly or the ecentric anomaly will define the motion of the satellite on its orbit.

[illegible] that described above. These variation in the satellite orbit are called *secular variations* and are of two type known as the *nodal regression* and the *rotation of the lines of the apsides* The nodal regression is a rotation of the orbit plane in the direction opposite to the satellite motion around the axis of rotation of the earth. The rate of this motion in degrees per day is given as

$$\overset{o}{\Omega} = -[10/(1-e^2)^2]\,(R/a)^{7/2}\cos i \qquad \ldots(9.24)$$

The rotation of the line of the apsides is the rotation of the ellipse major axis around the center of the earth on a fixed orbit plane. Apogee and perigee move then with respect to the earth, and the rate of motion of the argument of perigee is also a function of orbit inclination angle i, or

$$\overset{o}{\omega} = [5/(1-e^2)^2]\,(R/a)^{7/2}\,(5\cos^2 i - 1)°/\text{day} \qquad \ldots(9.25)$$

The critical value $i = \cos^{-1}(1/\sqrt{5}) = 63°24'$ stops this motion. Smaller values of i make the ellipse rotate in the same sense as the satellite motion along it. Higher values of i make the ellipse rotate in the opposite sense. The effect becomes smaller for higher orbits. For lower altitude orbits the earth's [illegible] the satellite orbit but for higher orbits the solar and

lunar gravitational fields are of much concern. For goestationary orbit these efects cause a change in satellite inclination by 1° per year. It may be noted that the inclination causes the satellite to move in the form of figure of eight (Fig. 9.5) which gives the corresponding amount of drift in distance (km) both in longitude and latitude of satellite. An inclination of 1° causes drift of satellite around 735.9 km in latitude side and 3.23 km in longitude side.

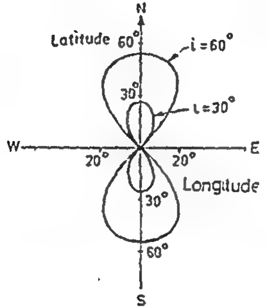
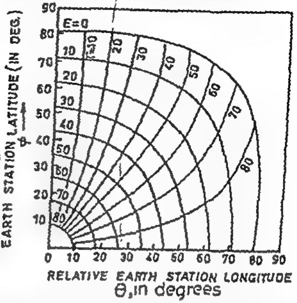


Fig. 9.5. Satellite's apparent movement in an inclined and synchronous orbit with respect to the ascending node

9.5. Look Angles

The look angles are the angles (coordinates) to which an earth station antenna must be pointed to communicate with the geosynchronous satellite. These angles are the azimuth (A) and elevation angle (E). These are calculated on the basis of a knowledge of latitude (ϕ) and relative longitude (θ) both in degrees of the earth station. Infact θ is the absolute value of the difference between the geostationary satellite longitude and that of the earth station. Azimuth angle is usually defined as the angle by which the antenna, pointing at the horizon must be rotated clockwise around its vertical axis, from the geographical north, to bring the antenna boresight into the vertical plane containing the satellite direction. Value of the azimuth angle is between 0° and 360°. Its value is calculated from Fig. 9.6 by determining

the value of angle γ from the chart and then deriving A from angle γ using the insert table. Angle γ may also be calculated from the geometry, of satellite orbit in the reference system shown in Fig 9.7. Angle γ can be calculated from the formula



True Azimuth	Earth station Quadrant
$A = 180-\gamma$	NW
$A = 180+\gamma$	NW
$A = \gamma$	SW"
$A = 360-\gamma$	NE

Fig. 9.6. Azimuth Angle γ and Elevation Angle E for Earth's Station Antennas

$$\gamma = \text{arc } t_g \,(t_g\, \theta / \sin\phi) \qquad \ldots(9.26)$$

The *elevation angle* is defined as the angle by which the antenna boresight ... the satellite direction from

from the chart given in Fig. 9.6. It is also calculated from the ... below :

$$E = \frac{\text{Arc } t_g \left(\cos\theta\cos\phi - \frac{R_e}{R_e + R_o}\right)}{[1-(\cos\theta\cos\phi)^2]^{1/2}} \qquad \ldots(9.27)$$

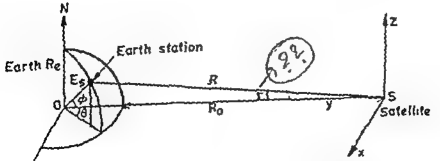


Fig. 9.7. Calculation of angle γ from the geometry of satellite orbit in the referene system.

where R_e is the earth radius = 6378 km and R_o = satellite = 35786 km.

The polarization angle ψ is defined as the angle between the polarization plane of a linear polarized wave transmitted by the satellite and the polarization plane of the earth station antenna. Angle ψ may be calculated from the chart of Fig. 9.8. It is also calculated (within an error less than 0.1° by the formula

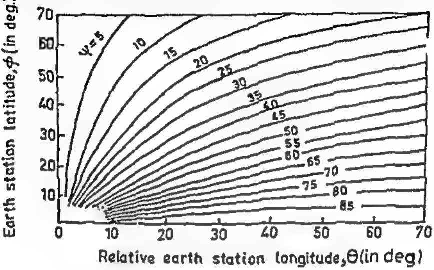


Fig 9.8. Polarization Angle of Earth Station Antenna.

$$t_g\,\psi = \frac{\sin\theta}{t_g\,\phi} \qquad \ldots(9.28)$$

It should be noted that for an observer positioned behind the antenna and looking at the satellite, rotation should be clockwise if the station lies to the east of the satellite meridian and anticlockwise if the station lies to the west of the satellite meridian.

9.6. Earth Coverage and Slant Range

In Fig. 9.7 the coordinates of the earth station may be written as

$$x = R_e \cos\phi \sin\theta$$

$$y = R_0 + R_e\,(1 - \cos\phi\cos\theta)$$

$$z = R_e \sin\phi$$

The range R (also called slant range) from satellite to earth station then would be given as

$$R^2 = R_0^2 + 2R_e\,(R_0 + R_e)\,(1 - \cos\phi\cos\theta) \qquad \ldots(9.30)$$

For $R_e / R_o \approx 0.178$, it is approximately

$$(R/R_0)^2 \approx 1 + 0.42\,(1 - \cos\phi\cos\theta) \qquad \ldots(9.31)$$

It can be seen from Eq. (9.31) that the maximum value of $(R/R_0)^2$ is 1.356 and if R^2 is approximated by R_0^2 it would lead to a maximum error of 1.3 db in the power link budget.

satellite is already shown in Fig. 9.2. In other words the maximum geometrical coverage is given by the portion of the earth within a cone with the satellite at its apex and tangent to the earth's surface. The apex angle (coverage angle) $2\alpha_{max}$ of this core is

$$2 \text{ Arc Sin} \frac{R_e}{R_e + R_s} = 17.4° \qquad \ldots(9.32)$$

This angle is also shown in Fig. 9.2 and is redrawn in Fig. 9.9. In Fig. 9.9 θ_s is the central angle that represents the angular radius of the satellite footprint. It is given by

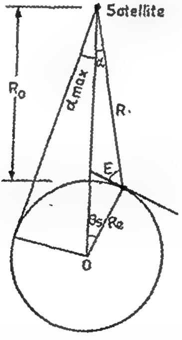


Fig. 9.9. Elvation angle and Coverage Angle with Reference to Synchronous Satellite.

$$\theta_s = 180° - (90° + E + \alpha) = 90° - E - \alpha \qquad \ldots(9.33)$$

For a geostationary orbit, corresponding to coverage angle α_{max}, the central angle θ_s is obtained from Eq. (9.33) by putting E=0 and $\alpha = \alpha_{max}$, this gives $\theta_s = 81.3°$. But as mentioned in Section 9.2, a minimum elevation angle of 5° is required then $\theta_s = 76.3°$. Thus not more than 76.3° of northern or southern latitudes will be covered by the geosynchronous satellite.

The slant range R may also be calculated in terms of elevation angel E as shown in Fig. 9.9. Its value would be

$$R^2 = (R_e + R_o)^2 + R_e^2 - 2R_e\,(R_e + R_o) \times \text{Sin}\left[E + \text{Sin}^{-1}\left(\frac{R_e}{R_e + R_o}\text{Cos}\,E\right)\right] \qquad \ldots(9.34)$$

which for E_{min} = 5° would give maximum slant range R=41,127 km which gives a satellite round trip delay of $2d/c$= 0.274 s where c is the velocity of light. To thus delay, delays caused by terrestrial extensions (which are of the order of 10-50 ms) are also added. However, because of the use of echo suppressor or echo cancellers the delay is not troublesome in telephone onversations.

9.7. Eclipse Effects

Solar eclipses caused by the earth and moon to the satellite are important as these affect the working of satellites and in particular the energy generated by solar cells is greatly affected then. Therefore the periodicity and duration of these solar eclipses are important. It should be noted that solar eclipse due to earth is of more importance than due to moon on the communication satellite as the former lasts for several days. In this section firstly the solar eclipse that due to earth would be discussed and then that due to moon would be discussed.

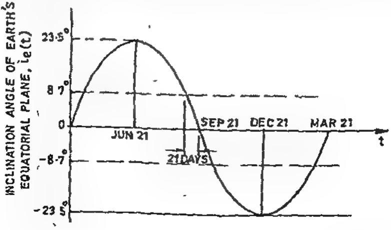


Fig 9.10. (a) Variation of the Earth's Equatorial Plane Inclination Angle $i_e(t)$.

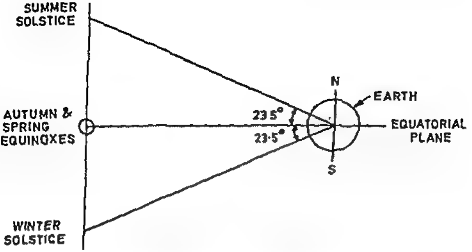


Fig. 9.10. (*b*) Apparent Movement of the Sun Relative to the Earth.

[illegible]

ically as

$$i_s(t) = 23.5 \operatorname{Sin} \frac{2\pi t}{T} \qquad ...(9.35)$$

where T is the annual period equal to 365 days and the maximum inclination angle $i_s(t)$ is 23.5°. At the spring and autumn equinoxes the inclination angle is zero whereas it is at its maximum on summer and winter solstices.

The satellite is always illuminated at the solstice. It goes the maximum duration of eclipse during equinoxes. The solar eclipse during equinox is as that shown in Fig. 9.11. Here the earth's shadow is considered to be a cylinder of constant diameter. The maximum shadow angle occurs at equinoxes and is given as

$$\phi_{max} = 180° - 2\cos^{-1}\frac{R_e}{R_o + R_e} \qquad ...(9.36)$$

which is same as that of coverage angle given in Eq. (9.32). Substituting value of $R_e = 6378$ km and $R_0 = 35786$ km (satellite altitude), $\phi_{max} = 17.4°$. Corre-
-onding to this shadow angle, the duration of eclipse for the geostationary
whose period is 24 hours can be given as

$$t_{max} = \frac{17.4^\circ}{360^\circ} \times 24 \cong 69.4 \text{ minutes} \approx 1.16 \text{ hrs} \qquad ..(9.37)$$

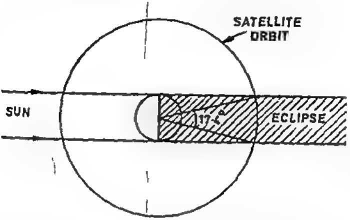


Fig. 9.11. Eclipse Due to Earth when Sun is at Equinox

The first eclipse day before an equinox and the last day of eclipse after an equinox correspond to the relative position of the sun such that the sun rays tangent to the earth pass through the satellite orbit. Such a situation is shown in Fig. 9.12. In these cases the inclination angle of the equatorial plane with respect to the direction of the sun is

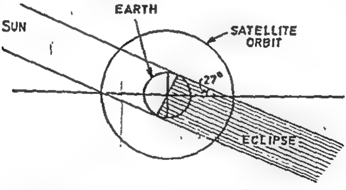


Fig. 9.12. Inclination of Earth at the First Day of Eclipse Before Equinox for a Geostationary Satellite.

$$i_s = \frac{1}{2}\phi_{max} = 8.7^\circ \qquad ...(9.38)$$

Corresponding to this inclination angle of the earth's equatorial plane, from Eq. (9.35), the time t from the first day of eclipse to the equinox and the time from equinox to the last day of eclipse may be derived as

$$t = \frac{365}{\pi} \sin^{-1}\left(\frac{87}{23.5}\right)$$

$$\approx 21 \text{ days} \qquad \ldots(9.39)$$

Thus from the first day of eclipse 21 days are needed to reach the equinox. This is shown in Fig. 9.10. (*b*) as well as in Fig. 9.13. Thus in total for 42 days the solar eclipse near equinox affects the satellite's working. It should be noted that at half of the daily duration period of eclipse the satellite crosses the plane formed by the sun and the earth's axis where the local time at the satellite's longitude is mid night. Thus the satellite services are interrupted at midnight and the satellite needs a battery backup.

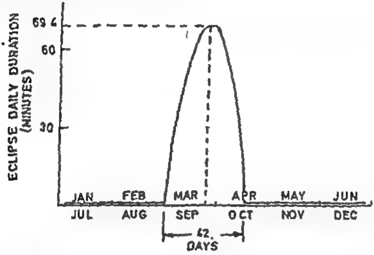


Fig. 9.13. Daily Duration of Solar Eclipse Caused by Earth.

The solar eclipse caused by moon to the geostationary satellite occurs when the moon passes in front of the sun. The eclipse occurs irregularly in time of duration and depth. Oftenly eclipses may occur twice within a 24 hr period. Eclipse duration may range from a few minutes to over two hours with an average druration of about 40 minutes. Compared to earth-solar eclipse, the number of moon solar eclipse range from zero to four with an averae of two per year. It is worthwhile to note that if the moon solar eclipse of long [illegible]

thermal reliability. In order to cope up [illegible] eclipses an energy reserve is provided with the satellite.

9.8. Satellite Placement in Geostationary Orbit

The placement of satellite in the geostationary orbit is carried out on the principle of *Hohmann transfer* and is as that shown in Fig. 9.14. Here the satellite firstly has the lower circular earth orbit at an altitude of around 300 or so. Then a velocity increment changes the satellite's lower circular earth into an elliptical transfer orbit with the perigee at *initial altitude (300 km)*

and with apogee at the altitude of final circular orbit (radius of the geosynchronous orbit is equal to 42,164.2 km). A second velocity increment then finally places the satellite into this desired orbit. The velocity increments are carried out by vaious auxiliary propulsion stages. There are three ways to carry out above procedure, of course depending upon the launch vehicle. The first technique is same as that mentioned above, *i.e.* placing the satellite in geosynchronous orbit from a circular low earth orbit. Space Transport System (STS) follows this technique. In the second technique, there is no initial circular orbit and the vehicle provides the necessary velocity at the perigee of the elliptical transfer orbit. Thus here only one velocity increment is required from the satellite at the apogee. This technique has been used by expendable launch vehicles such as Ariane, Delta or Atlas-Centaur launchers. In the third technique, satellites are directly placed into geostationary (geosynchronous) orbit. This is achieved by special expendable launch vehicles such as US Titan III C and the USSR Proton launchers.

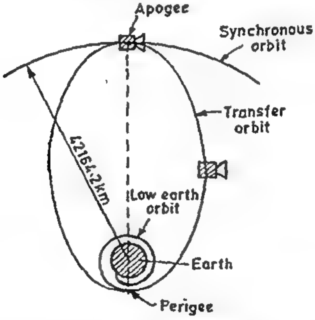


Fig. 9.14. Satellite Placement in Synchronous (Geostationary) Orbit from a low Earth Orbit.

The velocity of satellite (V_s) at the perigee and apogee of the elliptical transfer orbit can be calculated from Eq. (9.7), namely

$$V_s^2 = \frac{2\mu}{r} - \frac{\mu}{a} \quad \text{...(9.40)}$$

where a is the semi-major axis of the ellipse, μ is gravitational constant of the earth ($\mu = 398600$ Km^3/s^2). r is the distance from the center of the earth to the point at which the velocity V is required to maintain the ellipse. Thus at perigee (of 300 km), $r = 6678.2$ Km, $a = (6678.2 + 42164.2)/2 = 24421.2$ Km. The velocity is then $V_{p} = 10.15$ Km/s. At the Apogee, $r = 42164.2$ Km and there the velocity $V_{AS} = 1.61$ Km/s. Since the velocity in a synchronous orbit ($r = a = 42164.2$ Km) is $V_{cs} = 3.07$ Km/s so the required velocity increment at apogee is $\Delta V_{CS} = V_{CS} - V_{AS} = 3.07$ Km/S $-$ 1.61 Km/S $=$ 1.46 Km/S. This velocity increment value corresponds to a minimum and applies to a circulization manoeuvre when transfer orbit and circular orbit lie in the same plane.

The above discussions about velocity increment at apogee of transfer orbit is true when the launch is carried out at the equator (0° latitude). In case the satellite is launched from other sites (launching station latitudes other than 0°) then the satellite's final orbit would be a synchronous orbit with an inclination I greater than or equal to the latitude of the launch point. It is therefore then essential to have an *orbit inclination correction manoeuvre.* Since the inclination of *transfer orbit is the angle between the plane of the transfer orbit and* the equatorial plane, correction of this inclination will help in converting the transfer orbit plane into the equatorial plane. Fig. 9.15. shows this orbit inclination correction. This orbit inclination correction is obtained by applying a velocity increment at one of nodes of the orbit which will cause a resultant velocity vector in the equatorial plane. Thus the magnitude of the incremental velocity vector ΔV required to correct the inclination is

$$\Delta V = \sqrt{V_n^2 + V_{cs}^2 - 2V_n V_{cs} \cos i} \qquad \ldots(9.41)$$

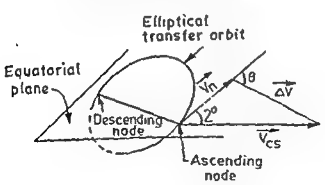


Fig. 9.15. Inclination Correction and Orbit Circularization

... at node and V_n is the satellite velocity in

$$\Delta V = \sqrt{V_{AS}^2 + V_{CS}^2 - 2V_{AS} V_{CS} \cos i} \qquad \ldots(9.42)$$

Thus for $i = 28$, $V_{AS} = 1.61$ Km/s and $V_{CS} = 3.07$ km/s, the incremental velocity required to correct the orbit inclination and to achieve orbit circularization obtained from Eq. (9.42) is $\Delta V = 1.81$ Km/s It is evident from Fig. 9.15 that the angle θ at which the main axis of satellie is correctly oriented relative to the satellite velocity in a plane perpendicular to the line of nodes is derived from expression given by

$$\theta = \text{Arc Sin}\left(\frac{V_{CS}\,\text{Sin}i}{\Delta V}\right) \qquad \text{...(9.43)}$$

Since V_{cs} is nealy equal to V_{AS} so θ is nearly equal to $2i$.

9.9 Station keeping

The importance of station keeping the satellite in its geostationary (synchronous) orbit has already been mentioned in Section 9.1 where the 'window' in which the satellite may be kept always is also explained. It is also mentioned there that a window corresponding to a drift of 75 km on the sphere containing the geostationary satellite orbit is allowed. This corresponds to an angular shift of $\pm 0.1°$ in longitude for the fixed satellite and also for broadcasting satellite services. This station keeping accuracy of $\pm 0.1°$ has been internationally standardized by CCIR. It is always essential that in station keeping whatever the orbit correction techniques be utilized, the propellent consumption should be minimum and therefore some kind of strategy is followed. The strategy usually has several steps as given below. Firstly the direction and speed of drift of the satellite is determined. Then by extrapolation prediction is made as to which day the satellite will escape the window and a few days before this date the true orbit is determined using a new series of measurement. After that calculations are carried out regarding the date, the amplitude and duration of the velocity increments required to modify the orbital parameters. Appropriate thrusters are then fired and then the effects of correction are monitored.

Compensation of the inclination increments correspond to *North-South (N-S) station keeping* and requires a thrust impulse perpendicular to the orbital plane. *East-West (E-W) station keeping* (as well as quick relocation to a different satellite position in the geostationary orbit) are obtained by applying thrusts in the orbital plane. The above mentioned station keeping accuray of $\pm 0.1°$ actually corresponds to *E-W* accuracy. Internationally there is no such demand on *N-S* station keeping accuracy. However, it should be noted that *NS* corrections are considerably more costly in terms of fuel expenditure for the reaction equipment (thrusters) and therefore for moderate *NS* movements correction are not carried out at all. For this reason, the satellite is launched into a slightly inclined orbit such that inclination decreases from its maximum value (i_{max}) to zero and then again increases to i_{max}. Then if the planned lifetime of the satellite is T_L years, i_{max} would be approximately

$$i_{max} = \frac{1}{2} i_{av} T_L \qquad \text{...(9.44)}$$

were i_w is the natural annual change of inclination *averaged over the lifetime* T_L. A typical value for long lived satellite is $i_w = 0.86°$ which corresponds to the velocity increment correction of $\Delta V = 460$ m/s. Compared to this, the required velocity increment correction for east-west station keeping of $\pm 0.1°$ is around 27 m/s which is much less than required for *NS* station keeping. Thus if the ground network could tolerate complete absence of *NS* corrections of the orbit of a nominally geostationary satellite, *more than 90% of the thruster fuel for station keeping may be saved.* This allows for an extra useful payload on board the satellite. Though this is an attractive tradeoff but involves careful consideration of the wider pointing or beamwidth margins of the antennas required in the absence of *N-S* station keeping.

9.10. Satellite Stabilization

Even if a perfect station keeping manoeuvre is carried out, the satellite may display motions about its center of mass. This will disturb the pointing of satellite antennas narrow beam towards the earth. It is therefore essential that the satellites be perfectly balanced. It may be noted that the disbalancing [illegible]

through a 24th period and cause wobbling of the spacecraft which requires to be damped out mechanically. This is achieved by the techniques called *Satellite stabilization or attitude control.*

The disbalanced satellite may display its motion on either of the three axes as shown in Fig. 9.16. These axes are termed yaw, roll and pitch axes. If *the satellite is stabilized about these axes*, the stabilization is termed as *three* [illegible]

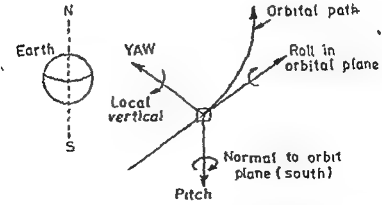


Fig. 9.16. Spin Axes of Geosynchronous Satellite

yaw, roll & pitch

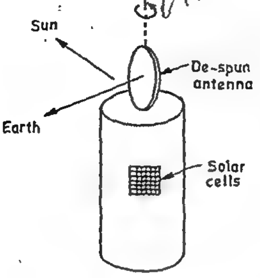


Fig. 9.17. Spin Stabilized Satellite

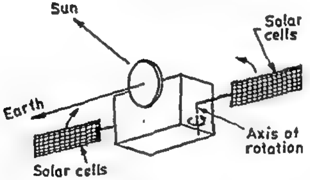


Fig. 9.18. Three Axis (body) Stabilized Satellite

nique may be used to stabilize the satellite. This kind of satellite stabilization is called *spin stabilization*. Fig. 9.17. Shows the spin stabilized satellite. Here the spin stabilization is achieved by rotation of the geostationary satellite body between 30 and 120 rpm creating an inertial stiffness which maintains the satellite spin axis perpendicular to the equatorial plane. The satellite spin axis is thus North/South oriented. The spin stabilization has the disadvantage that it requires the use of a de-spun antenna. Thus here the satellite is cylindrical spinning about the axis of the cylinder. Solar cells cover the cylindrical surface and antennas are mounted on a de-spun plateform. The despun section is kept stationary by counter rotation so that the antennas mounted on it are constantly pointing toward the earth. In the three axis body stabilized satellite as shown in Fig. 9.18 a spinning momentum wheel within the satellite establishes the same frame of reference as the spinning cylinder of the spin stablized satellite.

In this case, however the entire spacecraft is effectively the despun plateform which maintains its orientation in space relative to the momentum wheel axis. The solar cells in such kind of stabilized satellite are mounted on panels external to the spacecraft body, allowing them to be oriented toward the sun. The control system is therefore more complex for a three axis body stabilized satellite.

9.11. Review Questions

1. Explain Kepler's laws of planetary rotation. How are these applied to the case of geostationary satellite?
2. Name the orbital aspects which are of importance in synchronous satellite communication. Explain these aspects in brief.
3. Explain as to how the synchronous orbit of a geostationary satellite is being determined ? Also explain as to why the geostationary satellites are not capable of illuminating polar regions ?
4. What are the orbital parameters required to determine a satellite's orbit ? Name and explain them.
5. Explain as to how the location of satellite in an orbit is carried out with respect to earh ? What are direct and retrograde orbits ? Also explain the ascending, descending nodes, right ascension and nodal regression.
6. What is meant by look angles? Explain them with reference to a geostationary satellite and the earth station
7. How can one determine the earth coverage and slant range for geostationary satellite ? What are the maximum vlues of the two parameters ?
8. Explain as to how does the solar eclipse affect the working of a communication satellite ? Mention the duration and the month when the eclipse effects are maximum ?
9. [illegible]
10. What is meant by station keeping of satellite ? Explain its significane and also the methods to achieve it. What are N-S and E-W station keeping?
11. What is meant by the satellite stabilization ? Explain the importance of stabilization. Also explain the spin stabilization and three axis body stabilization of satellite

9.12. References

Alongwith the books mentioned in references of Chapter 1, following books and articles may also be referred.

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TEN

Communication Satellite Subsystems

10.1. Introduction

Geostationary communication satellite is a very complex system that

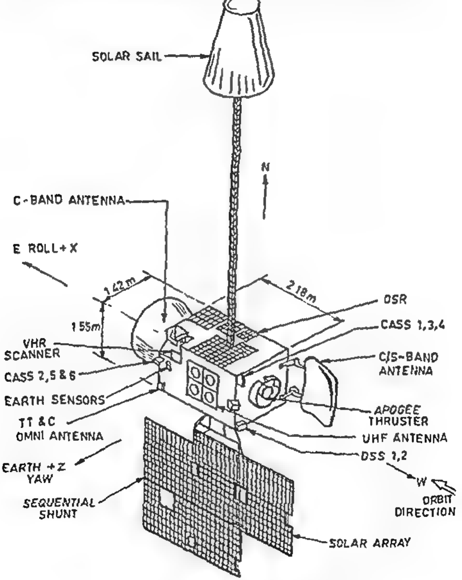


Fig 10.1 INSAT-1 on - Orbit Satellite Configuration

comprises of several subsystems which have their own significance. These subsystems may be divided into two groups, namely the communication subsystems and the other subsystems (also called common subsystems all taken together) which support the communication subsystems. The communication subsystem is also oftenly termed payload that is mainly comprised of repeaters and antennas and it performs the primary mission. The other subsystems (common subsystems) have a common bus or platform. These other subsystems are power, stabilization, propulsion, station keeping, attitude control, and telemetry, tracking and command. Fig. 10.1 shows INSAT-1-on-orbit satellite configuration in which these subsystems are well evident. Table 10.1 lists these subsystems indicating their important functions and parameters of importance. However, it should be remembered that all the subsystem work with high reliability and all the satellite projects be of minimal mass with least power consumption. It is also essential that these subsystems follow the electromagnetic interference (EMI) and electromagnetic compatibility (EMC) requirements.

Table 10.1

Communication Satellite Subsystems, their Functions and Parameters of Importance

Subsystem	*Functions*	*Parameters of Importance*
Repeaters	Amplify signals and transmit back	Noise figure, linearity and output *rf* power
Antennas	Receive and transmit signals	Coverage, gain
Electric Power supply	Provides electric energy at various voltage levels	Power, voltage regulation
Structure	Supports equipment	Stiffness
Attitude & Orbit control	Attitude stabilization, Orbit determination	Accuracy
Thermal Control	Temperature Regulation	Heat dissipation capability
Propulsion	Provides velocity increments and torques	Specific impulse, Mass of propellent
Telemetry, tracking & command	Exchange of house-keeping data with control centre	Number of channels, security of communications

10.2. Electric Power Supply

[illegible]

obtained from solar cells. But during the first few hours following the injection into transfer orbit and prior to deployment of the solar panels, the mechanical accumulators provide the electric power supply

especially those of USSR, thermonuclear energy source are also

to dangers involved with nuclear fuels especially with their shielding etc. nuclear generators are not used in communication satellite for supplying electric power.

Solar cells are photovoltaic cells that convert solar radiation to electricity which is then converted to usable voltage levels in a power supply. The normal conversion efficiency of solar cells is around 12% to 15% and the typical satellite solar cell arrays generate 1 to 2 KW of power. The above conversion efficiency of solar cells decreases under the effect of the *radiations* and drops by about 30 to 35 per cent in seven years. The main radiations come from protons especially during solar flares and therefore solar cells are covered with [illegible] 18%.

Since the satellite goes under solar eclipses which is of concern during Equinox (as discussed in Section 9.7) provision is made for the storage of power that can be used during the solar eclipse. For this purpose electro-chemical accumulators like those of nickel-cadmium accumulators are used. These are hermetically sealed ones and are designed to supply power required [illegible] *(DOD)* represents the percentage of the maximum stored energy which is [illegible] weight ratio of nickel-hydrogen batteries may allow sufficient extra station [illegible] batteries are regularly and continuously being charged by solar cells. Here the battery voltages are between 20 to 50 V with capacities between 20 to 50 *ampere hours*.

[illegible] cold space (shadow). Hence the average temperature is relatively low (between 20 to 30°C, say around 25°C). At this temperature the solar cell efficiency is [illegible] which is reduced by 22% at the end of the satellite life due to various [illegible]. Therefore about 15% extra area of solar cells is usually provided

as an allowance for aging. In the three axis body stabilized satellite, wings of solar panels are used which are folded in transfer orbit and then full power becomes available. These are required to have atleast one revolution per day [illegible] complexity of a deployed solar array drive motor and therefore for low power satellites spin type of stabilization is preferred.

10.3. Attitude and Orbit Control

The necessity of attitude and orbit control of the communication satellite was discussed in Sections 9.9 and 9.10. Corrections to achieve these are obtained by certain manoeuvres. These are carried out by control loops based on error detection and decision systems. These also involve the use of telemetry, telecommand (TTC) subsystem for information exchange between satellite and earth. The attitude control may be *passive* or *active*. In the former case the required attitude corresponds to a position of stable equilibrium of the satellite. In the latter, the satellite is unstable, or insufficiently stable within the desired attitude configuration. For active attitude control four operations are needed, namely (*i*) detection of the satellite altitude, (*ii*) comparison with the reference axis, (*iii*) determination of the corrective torques and (*iv*) correction of the attitude by actuators mounted on the satellite.

To carry out above mentioned operations various kinds of sensors are used which infact detect the satellites altitude. For this purpose a variety of sensors such as sun sensors, earth horizon sensors, stellor sensors, inertial sensors, radio frequency sensors and laser sensors are being used. However, in most of the communication satellite systems the earth and sun sensors are used for attitude control. From these sensors the attitude is determined. The position of earth sensor is evident typically in INSAT-1 of Fig. 10.1. Actually the earth sensor is a passive infrared device that has a pencil beam field of view and operates in the 14-to-16 μm wavelength carbon dioxide absorption band. It senses the infrared rays radiating from the earth's surface by scanning the boundary of the horizon between the earth and space. Normally two such earth sensors are used. They are canted about 5° north and 5° south of the spin plane respectively and provide the output radiance pulse as they scan the earth. In case these pulses are in-phase the attitude of the satellite is considered to be correctly maintained otherwise the spin axis would be inclined at an angle. In such a case the phase difference of the output pulses of North earth sensor and south earth sensors is utilized to control the attitude of the satellite. These are capable of allowing the attitude determination to an accuracy of $\pm 0.02°$. It may be noted that earth sensors are sometimes also called horizon sensors.

The sun sensors provide data which are used primarily during transfer orbit. It has a fan shaped field of view and operates in visual spectral range.

Out of the above three units of propulsion subsystem the low thrust actuators are of much importance for geostationary orbit as these are responsible for keeping the satellite in orbit with its perfect attitude till its life end. The low thrust actuators or simply the thrusters can be either chemical ones or the electrical ones. The chemical thrusters have a thrust level of between 0.5 N and few 10000 N. On the other hand the electrical thrusters produce thrust only in between 2 and 10 mN and therefore chemical thrusters are being used in communication satellites. It is essential for a thruster that it should provide the specific impulse with smaller mass because weight on board satellites is limited.

In chemical thrusters gasses are generated at high temperatures by chemical reaction of propellents which may be either solid or liquid. The gasses are then accelerated by a nozzle. Solid propellent motors are used to provide the required velocity increment for orbital injection. The most popular liquid propellent is hydrazine (N_2H_4) which vaporizes and decomposes when in contact with a catalyst and thus produces a hot gas. This hot gas is a mixture of nitrogen, hydrogen and ammonia at temperatures of 900°C. A satellite typically would need 200-300 pounds of hydrazine on board to carry out all of its functions over its life time. Some satellites use electrothermal hydrazine thrusters (EHT) that provides the large specific impulse of the order of 300s. Here the temperature of the gas before existing through the nozzle may reach upto 1900°C. These provide a considerable savings in the mass of fuel to be carried with the satellite.

A further savings over the conventional combination of a solid apogee kick motor and a hydrazine reaction control system is being obtained by the use of bipropellent spacecraft propulsion systems for both the geostationary satellite orbit injection and on-orbit control. The bipropellent systems are based on spontaneous combustions resulting from the contact of two propellents for instance monomethyl hydrazine (combustible) and nitrogen tetroxide (oxident).

The electric thrusters provide thrust by accelerating ionized mass in an electromagnetic or electrostatic field. Though it gives low thrust (less than 0.1 N) but the specific impulse is very high (1000 to 10000s). However it needs a high voltage power supply that means an increase in the size of solar arrays. Electric thrusters are mainly of two types, the plasma thrusters and the ion thrusters. Plasma thrusters employ a solid fuel rod (Teflon) that is spring fed to the thruster. In ion thrusters, charged particles are accelerated to high velocities by means of a high voltage grid system. Thus, it is evident that these electric thrusters are capable of providing specific impulses as high as 8000 to 10000s and so in principle the on board propellent mass of a electric thrusters should be lower compared with chemical thrusters. But as mentioned already, these demand an additional solar energy and so require an increase in the size of the solar arrays. These are therefore much useful only for extended satellite life time (more than seven years).

10.5. Repeaters

Repeaters and antenna together make the communication sub-systems of communication satellite. These provide the receive and transmit coverage for the satellite. Repeaters are also termed transponders. It performs two basic functions, namely (*i*) the amplification of signals from an input power of the range of -100 dbW to an output power of about 10 dbW (around 110 db gain) and (*ii*) the frequency down conversion (frequency translation) that avoids interference between transmitted signal and the weak incoming signal. The repeaters which perform the above functions are conventional repeaters. Sometimes there is also a provision of detection and demodulation process in the satellite transponders. Such transponders are called *regenerative transponders*. Fig. 10.2 indicates the block diagram of a conventional satellite repeater. Here the front end electronics is responsible for receiving the up link carrier, carrier processing for frequency translation and the power amplifier for bringing the signal to the desired power level. In the regenerative repeater the front end electronics would perform the receiving and detecting the uplink carrier, carrier processing for demodulation of the detected uplink at lower carrier frequency and the power amplifier for bringing the demodulated carrier to the desired power level. There are certain advantages in regenerative repeaters over conventional repeaters such as advantages in decoding, generation of spot beams (power concentration) and interference rejection.

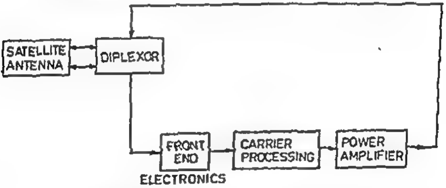


Fig. 10.2. Block Diagram of a Conventional Satellite repeater.

[illegible] antenna feeds.

The front end electronics system has usually the units as that shown in block diagram of Fig. 10.3. It consists of RF filtering, equalization and amplification. RF filters are typically constructed as microwave filters (waveguide filters) which are actually the integrated circuits and allow better packaging, lower weight and require less power. These filters are designed to achieve desired mask, noise rejection and equalization. Further, they should not have any significant contribution to circuit noise. Depending upon the requirements, either of the Butterworth, Chebyshev, Bessel and Legende filters [illegible]

distortions of the RF filters they themselves do not cause any attenuation distortion. In most of the present day communication satellite repeaters dual mode filters using cavity coupling are being used. These have centre frequency to band width ratios of about 10^4 at *C* band and about 10^3 at *K* bands. Thus at *C* band carrier filters have RF bandwidth of about 36 MHz.

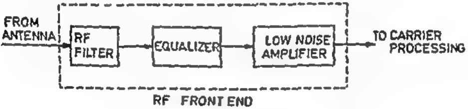


Fig. 10.3. Block Diagram of Front end Electronic System.

The low noise amplifiers have high gain characteristics. These are basically solid state microwave amplifiers such as tunnel diode amplifiers (TDA) having their inherent low noise contributions and moderately high power gains. Such LNAs are being universally used for *C* band and *K* band satellites. TDAs have the disadvantages of decreasing gain values at the higher microwave frequencies (>10 GHz) and so now are being replaced by Field Effect Transistor amplifiers for *K* band satellite.

The carrier processing equipment determines whether the repeater is conventional one or the [illegible]

as shown in Fig. 10.4. These may be RF-RF translation, RF-IF translation, IF remodulation and demodulation-remodulation. In Fig. 10.4 (*a*) a direct RF-to-RF conversion is carried out using a single mixer system. In the second method [Fig.10.4(*b*)] double conversion namely the RF to IF and IF to RF is carried out using a single local oscillator [illegible]

inserted) at the satellite before return [illegible]
the regenerative frequency translato [illegible]

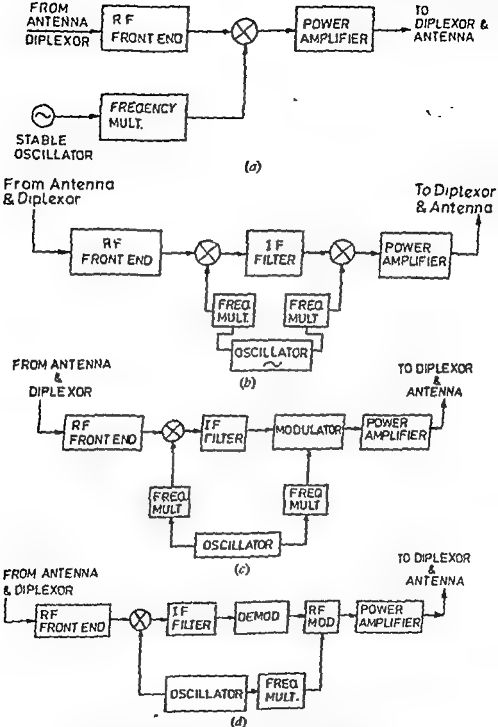


Fig. 10.4. Various frequency translation systems
(a) RF-RF Translation (b) RF-IF-RF Translation (c) IF Remodulation
(d) Demodulation-remodulation

frequency translators or the remodulating processors involve a stage of modulation that generates the return carrier. In Fig. 10.4 (*c*) it is carried out by first translating the uplink RF spectrum down to a low IF band and then modulating the entire IF onto the return RF. In Fig. 10.4 (*d*) firstly the uplink carrier is demodulated to baseband and then this baseband is remodulated onto [illegible] transmitted with the carrier modulation to be recovered during the demodulation and the satellite telemetry to be inserted into the baseband for downlink modulation. It may be noted that often transponder signal processing includes hard limiting following frequency translation. Such hard limiters are non-linear device and are usually followed by bandpass filters tuned to the input carrier frequency. Such combined limiter-filter is also referred to as a *bandpass limiter (BPL)*.

After frequency translation, the next unit of repeater is the power amplifier. Travelling Wave Tube Amplifiers (TWTA) are commonly used as power amplifiers for satellites. The size of TWTA depends on the mission and their typical values are such as output saturated power: from 8.5 to 20 W (150 to 250 W for direct broadcasting applications), saturated gain: about 55 dB, carrier to intermodulation noise power ratio at saturation: 10 to 12 dB and AM/PM conversion coefficient: about 4.5°/db. Since the TWTA establishes the transponder output power so it is normally operated near saturation to achieve the desired output. Further since TWTAs amplify primarily the constant amplitude carriers so variations in input carrier amplitudes during amplification may produce an undesired phase interference on the amplified carrier. Thus TWTA is the dominant non-linear device in the transponder that may affect the link signal performance significantly. Its effect on FDMA has already been discussed in Section 3.9. It is therefore necessary to have proper input control of the operating drive power of TWTA. This is being achieved by using a BPL-amplifier combination in front of high power TWTAs. It would be worthwhile to mention here that with the emerging solid state technology, solid state power amplifier (SSPA) are also recommended in place of TWTAs. These SSPAs make use of GaAs FET devices and are lighter in weight, more linear and offer a significant improvement in reliability which eventually would provide increased transponder capacity.

The above has been the discussion for the satellite repeater which has got single channel only. In case it is channelized one then the return *transponder* will refer to *one channel* of the channelized satellite repeater. Thus whereas the past satellite repeaters were of single channels the modern satellite repeater have several channels because of the availability of present day technology of reduction of weight, volume and power loss of the channel elements, *e.g.* filters, driver, attenuator, TWT etc. Moreover, the technology of launching satellites with heavier payloads has also considerably improved and thus allowing for more channels in satellite repeater. The Indian National Satellite INSAT-1 has 12 channel satellite repeater.

In such channelized satellite repeaters the two additional units are used, namely the input multiplexers (IMUX) and the output multiplexors (OMUX). The input multiplexer separates the 500 MHz bandwidth into individual transponder channels whose bandwidth depends on the satellite's mission. For example, a 500 MHz bandwidth can be divided into 8 transponder channels with a centre-to-centre frequency separation of 61 MHz. With the frequency reuse, in such a case there would be altogether 16 transponder channels in the satellite. The input multiplexers usually consist of input circulators, input filters, group delay equalizers, amplitude equalizers and output circulators. Fig. 10.5 indicates the basic block diagram of such an input multiplexer system.

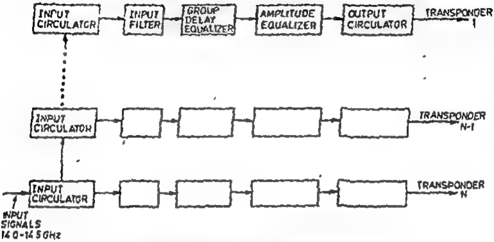


Fig. 10.5. Basic Block Diagram of Input Multiplexer System.

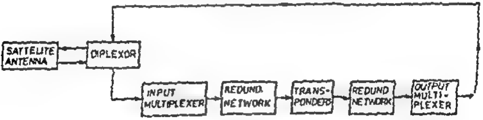


Fig. 10.6. Basic Block Diagram of a Channelized Satellite Repeater.

... TWTAs of different channel ... for retransmission to ... 1 output out of band ... to suppress signal harmonics

10.6 Antenna Systems

Antennas are another part of satellite communication subsystem. In fact the antennas on board the satellite serve as an interface between the earth stations on the ground and various satellite sub-systems during operations. Antennas receive the uplink signals and transmit the downlink signals. In addition they provide a signal link for the satellite telemetry, command and ranging systems which in conjunction with the attitude control subsystem provides beacon tracking signals for precise pointing of the antenna toward the earth coverage areas. The design of a satellite antenna is conditioned by the required coverage. It should be remembered that antennas are one of the key elements in a satellite communication system since their gain values directly determine the amount of received power. However, it is the antenna pattern that describes the antenna characteristics required in the satellite communication. These are the gain (maximum value of the gain pattern), the beamwidth (a measure of the angle over which most of the gain occurs). In satellite communication it is essential that the desirable antenna patterns should be highly directional with high maximum gain concentrated over a narrow bandwidth with negligibly small sidelobe transmission.

Satellite communication system uses a variety of antenna system. These may be linear dipole, helix, horn, antenna array and the parabolic reflector. However, the parabolic reflector is the most commonly used one as it gives a [illegible] antennas such as dipoles, horns or helics produce a combined beam with directivity. Arrays have the advantages that by properly selecting the phase shifts between array elements the directivity of the beam may be oriented in a given direction. Moreover, the gain of arrays increases with the number of array elements and hence high gain is achieved with large arrays. Also, here the beamwidth changes with the beam direction, being narrowest for broadside beams and larger for axis beams. It is due to this reason that in most of the present day communication satellites phased array antennas are being used.

Among the antennas mentioned above, satellite communication utilizes reflector antenna both in communication sub-system as well as in the earth station. This reflector is the [illegible] an offset configuration can more easily be accommodated in satellite design especially when it is necessary to deploy the reflector after launching. Inspite of these advantages,, offset reflector, however, generates cross polarized component in the antenna radiation field when it is illuminated by a linearly polarized field and similarly when circular polarization is employed, the

antenna beam is squinted from the electrical boresight. These problems create trouble when frequency reuse technique is used by orthogonal polarization. In frequency reuse two reflectors are needed for generating orthogonally polarized beams one for each polarization. In actual practice these two reflectors are incorporated into a single physical structure. In such cases the single structure consists of two polarization-selective grided offset parabolic reflectors stacked one behind the other to facilitate aperture sharing. These two reflectors are fed by two independent multihorn arrays which do not interfere with each other either physically or electrically.

To provide high gain for the coverage areas, multiple beams or shaped beams may be required by the communications antenna. These may be designed by using a primary feed composed of an array or a set of feeds located in the vicinity of the focal point. Thus if the primary feed would consist of an array of feeds driven at same frequency by a beam forming network, the combination of the electric fields radiated by the individual feeds would result in shaped beam. Separate offset feeds generate distinct beams at a specific frequency and in a given direction, resulting in a multi-spot beam coverage. This technique is thus capable of providing a beam lattice coverage when the number of beams (and hence of feeds) is not too large. In large communication satellites which operate at several frequency bands with different coverage zones, the primary feeds are designed in such a way that several primary feed arrays share one reflector. The problem of putting all such feed arrays at a focal point is overcome by the use of polarization and/or frequency sensitive surfaces which allow orthogonally polarized waves or waves at different frequencies to be focussed at distinct locations. It would be of importance to [illegible] it is essential that the antenna [illegible]

east-west (pitch) and north-south (roll) beam pointing errors and $\pm 0.2°$ for beam radiation (yaw) errors. Lens antennas are also used in multiple beam antenna technique and these have the advantages over offset reflector antennas to be axisymmetric and hence offering large cross polarization isolation.

Conclusively, in the satellite antenna it is essential that the antenna mainlobe should be such that the energy is concentrated towards the earth [illegible] the EIRP. However, it is found that if the [illegible]

10.7. Telemetry, Tracking & Command (TTC) Sub-System

TTC sub-system is the most essential sub-system of the satellite because it keeps the satellite in working order and all sorts of manoeuvre are carried out through them. TTC sub-system involves the earth station and infact is a part of satellite management task. The main functions of TTC sub-system are, namely ; (*i*) the transmission of house-keeping information and status of the satellite to the ground control station, (*ii*) carrying out angular and range measurement to permit localization of the satellite and (*iii*) receiving command signals from the ground control station to initiate attitude and station keeping manoeuvres and operations of the onboard equipments. For these functions frequencies used are at vhf or in (S band) during launch phase and in the frequency band allocated for main satellite telecommunications (6/4 GHz) during on station. It should be noted that in TTC sub-system, tracking is primarily done by the earth station.

The telemetry system provides a data stream to the ground that reports on each of the satellite sub-systems independent of any other communications [illegible]

conditioning unit, current drawn by each sub-system, critical voltages and currents in the communication electronics, temperature of other sub-systems, position of switches, altitude etc. Thus there are over 100 different kinds of sensors mounted on the satellite for the purpose. There is a separate telemeter transmitter in the satellite which transmits the telemetry data *via* the communication antenna when the satellite is in orbit and in normal on station. When the satellite is in transfer orbit, the telemeter transmitter is connected to a TWTA in the satellite repeater. This then transmits telemetry data *via* an omni antenna mounted on the satellite. The telemetry data are digitized and transmitted as frequency of phase shift keying (FSK or PSK) of a low power telemetry carrier using time division techniques. The TTC earth station contains the necessary equipment to insert commands, receive and interpret the telemetry and compute orbital parameter.

For command operation, the satellite contains a receiver which works only for command signals transmitted from TTC earth station. Through this receiver the command sub-system controls the satellite operation through all phases of the mission by receiving and decoding command from the TTC earth station. The command sub-system also generates a verification signal and upon [illegible]

is used for command and ranging. Actually during the launch phase and injection into geostationary orbit a back-up system is used which provides control of the apogee boost motor, the attitude control system and orbit control thrusters, the solar sail deployment mechanism (if fitted), and the power

conditioning unit. This back-up system works with the omni antenna mentioned above. Once the satellite is in geostationary orbit, the main TTC sub-system works.

Tracking consists of determination of the current orbit of the satellite. This is done by determining the range which in turn determines the orbital elements. The TTC earth station can observe the Doppler Shift of the telemetry carrier or beacon transmitter carrier to determine the rate at which range is changing. Another way of determining the change in orbit is by using the velocity and accelerator sensors on the spacecraft that establish a change in orbit from its last known position. Some other methods such as triangulation method of transmission and reception of sequences of pulses (ranging tones) etc. may be used to determine range. The telemeter transmitter serves also as the downlink for the ranging tones. With such techniques and precision equipments at TTC earth station it has been possible now a days to determine *the position of satellite within 100 m.*

10.8. Thermal Control Sub-System

Thermal control of various satellite sub-systems are essential so that the satellite may work successfully till its whole life. The thermal control sub-system therefore maintains equipments and structure of the satellite within specified temperature ranges both during operation and idle time. Since the satellite is in synchronous orbit where extremes of solar radiations are present so special care regarding extreme heat and extreme cool (when the satellite parts are in shadow), temperature variations is needed. Similarly, during operational and transfer orbit phases the temperature variation requirements are different. This has made necessary for the complete thermal control of the satellite so that as the sun moves around the satellite once every 24 hours the temperature range variations around various satellite sub-systems remain in the prescribed range. The typical temperature ranges for various satellite equipment as allowed are : batteries 0°C to +20°C, solar cells -100°C to +50°C, electronic equipment -10°C to 60°C, propellent tanks +10°C to 50°C and infrared sensors -20°C to +45°C. Thus the mean temperature of the satellite is [illegible]

The convection heat exchange due to vacuumm is not there.

As a matter of fact all the electronic packages and other components that [illegible]

Further the absorptance α and emittance ξ of the surface finish with respect to solar radiation conditions for various materials are also studied. In the satellite payloads it is essential to dissipate heat and therefore radiators with a very low α/ξ finishes (α about 0.08, ξ about 0.75) are employed. These consist of fused silica mirrors width silver backing, called optical solar

reflectors (OSR) or second surface mirrors (SSM) made from plastic (Teflon, Kapton or Mylar) sheets with silver or aluminium backing. These reflectors are located on the north and south panels so that they may efficiently radiate their heat towards outer space since the north and south panels are least affected by daily variations in solar incidence. Such types of thermal control systems are passive ones and are based on multilayer-superinsulation blankets which are composed of alternate layers of thin Mylar and Kapton films coated with vacuum deposited aluminium. Such passive thermal control systems are capable of providing high isolation between the satellite inside parts and outer space.

In addition to these passive thermal control systems there are also various active thermal control systems which maintain the temperature of equipments inside the satellite. These active thermal control systems are such as heat pipes, hinged flaps, multiple blade louvres and electrical heaters. The heat pipes allow adiabatic transfer of heat from heat sources to radiators by successive vaporization and condensation of a fluid at the two extremities of the pipe. The fluid used have high latent heat and therefore the heat pipes provide a high capacity for heat transfer with small temperature differences. The hinged flaps and multiple blade louvres carry out arrangements for covering the radiator areas or exposing them as per requirement. The electrical heaters provide the thermal controlling either through telecommand signals or thermostat. Thus it may be seen that the satellite thermal control systems are quite complex and essential ones. Their requirement and design vary from satellites to satellite. For example, the spin stabilized satellite will need a different thermal control system as compared to a body fixed satellite.

10.9. Structure Sub-System

This sub-system supports the equipment carried by the satellite for communication and other purposes. Therefore stiffness is of major concern here. During launch phase where mechanical stresses may be highest the structure sub-system plays a major role. Similarly the structure sub-system ensures correct positioning of onboard equipment such as alignment of sensors, thrust axes of the thrusters, axes of antenna etc. The structure sub-system allows the various separations and deployments depending upon the satellite launch vehicles. Finally it avoids electrical charge accumulation. Though the structure sub-system carries out so many essential duties, it is necessary that its mass should be only 6% of the total satellite weight. Therefore, structural materials which are light weight and have resistance to deformation such as aluminium and magnesium alloys, honeycomb panels, bonded assemblies and carbon fibre reinforced plastic materials are used for structure purpose.

10.10. Reliability of Satellite Sub-System

It is expected that the satellite should work satisfactorily over its specified life. The reliability is the parameter through which such characteristics of the satellite operation is expressed. In fact reliability is the probability that the system will perform satisfactorily over its specified life. Since the satellite involves mostly electronic equipment and components so the reliability of

satellite sub-systems will depend on the probability of failure of these electronic components. The probability of failure of electronic components is like a bath tube curve as shown in Fig. 10.7. In other words, for electronic components the probability of failure is higher at the beginning of life-the burn in period-than at some later time. Also as the component ages, failures become more likely. Thus once the satellite is in synchronous orbit, it can not be repaired and so several steps are already taken before the launch itself so that components remain useful for most of the satellite life time. For this purpose the components are rigorously tested under stimulated space and environmental conditions and then these are fitted with the satellite payloads.

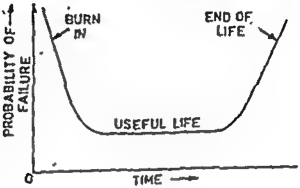


Fig. 10.7. Probability of Failure (Bath Tub) Curve.

Mathematically the reliability of a device or sub-system is defined as

$$R(t) = \frac{N_s(t)}{N_0}$$

$$= \frac{\text{Number of surviving components at time } t}{\text{Number of components at start of test period}} \quad \ldots(10.1)$$

Another important parameter in reliability studies is the mean time before failure MTBF defined as

$$MTBF = m = \frac{1}{N_0} \sum_{i=1}^{N_0} t_i \quad \ldots(10.2)$$

where t_i represents the time after which the *ith* device fails. MTBF is related to average failure rate λ by the formula

$$\lambda = \frac{1}{MTBF} \quad \ldots(10.3)$$

Failure rate λ is often given as the average failure rate per 10^9 hours. In terms of λ the reliability of the sub-system or device of Eq. (10.1) is given by

$$R = e^{-\lambda t} \quad \ldots(10.4)$$

which indicates that the reliability of a device decreases exponentially with t. In other words, after infinite time there will be zero reliability indicating a certain failure. However, in practice the end of useful life is usually taken to be the time t_e at which R fails to 0.37 or $(1/e)$ which is when

$$t_e = \frac{1}{\lambda} = m \qquad ...(10.5)$$

Eqs (10.4) and (10.5) indicate that the probability of a device failing has an exponential relationship to the MTBF. This is represented by the right hand end of the bathtub curve.

It must be of importance to mention here that if proper redundancy is maintained in the satellite, its reliability would be improved. Actually it is mainly with the TWTA in repeater for which redundancy is mostly provided. This is because of the fact that TWTA has a limited life time. Redundancy in most of the satellite systems is provided by a series, parallel or switched connections. Sometimes hybrid arrangement such as series/parallel connection is also provided. In practice the series/parallel connection is widely used in communications satellite transponders to provide redundancy of the high power amplifier. Oftenly a combination of parallel and switched redundancy is used to combat failures that are catastrophic to one transponder channel and to the complete communication system. Another way of improving the relationship that has been also sometimes widely discussed is by derating, i.e. by reducing maximum power consumption, voltage, current, temperature or some combination of all. Actually derating reduces the wear out by a geometric relationship to the amount of derating applied.

10.11. Review Questions

1. Explain various satellite sub-systems telling their important functions and characteristics.
2. What kind of electric power supply is used in a satellite ? Explain as to how precautions are taken for hostile environment regarding the smooth electric supply to various electronic components.
3. What are the attitude and orbit control sub-systems ? Explain as to how these perform their functions.
4. What is the propulsion sub-system ? Explain its constituent and their functions. Which is the most popular propellent being used ?
5. What is the communication sub-system ? Of which units it is composed of ? Explain the construction of a repeater telling the difference between a simple repeater and a regenerative repeater. What is the difference between a repeater and a transponder ?
6. What kinds of antenna systems are being used in satellite communication sub-system ? What is the multiple beam technique ? What precautions are taken in mounting the antennas on spin stabilized and body fixed satellites ?
7. [illegible]

8. Explain the working of Thermal Control sub-system ? What kind of thermal control sub-systems are being used in satellite ?
9. What is structure sub-system ? What kind of operation does it perform ? Which materials are preferred for the design of this sub-system ?
10. What do you mean by the reliability, mean-time before failure, effective failure rate as applied to satellite sub-system and components ? How are these related to each other ? Explain the 'bath tub' curve.
11. What is the redundancy and why is it necessary for the satellite sub-system particularly in repeaters ? How can the redundancy be achieved by series, parallel and switched connections ?

10.12. References

Alongwith the references mentioned in previous chapter, reference is also made to

1. Indian National Satellite System, bulletin issued by ISRO, June, 1988.
2. Gagliardi, R.M., Satellite Communication, CBS Publishers and Distributors, New Delhi, 1987.
3. Avduyevsky, V.S. and Ushensky, G.R., Scientific and Economic Oriented Space Systems, Mir Publishers, Moscow, 1988.

ELEVENTH

Satellite Earth Station

11.1. Introduction

Satellite communication is not complete without earth station which in fact transmits to and receives from satellite. The basic considerations of earth station are already discussed in Chapter 1 and the elementary block diagram is given in Fig. 1.2 Earth station may be located also on a ship at sea or on an aircraft but even then it is called earth station as it maintains communication link between earth and space or it forms the earth based end of the earth-space link. Fig. 1.2 [illegible]

[illegible]

may be as large as 30-m diameter in the INTELSAT network or as small as 0.7 m for reception of direct broadcast satellite television (DBS-TV). For deep space communication, the antenna size may still be larger.

Though every earth station would consist of above four major sub-systems but they can be classified according to the variety of equipments needed depending upon [illegible]

[illegible]

CATV systems and in direct TV broadcast satellite systems. Transmit only [illegible]

[illegible]

feature that is common to all the earth stations is the need to achieve a low system noise temperature in the receiving channel.

11.2. Earth Station Design Requirement

There are at least 8 important requirements that most of the earth stations have to meet. These are : (*a*) high gain in the direction of wanted signals, (*b*)

low gain in the direction of unwanted signals, (*c*) low effective noise temperature for the entire receiving system, (*d*) high antenna efficiency, (*e*) continuous satellite pointing with a specified accuracy, (*f*) minimum performance variations caused by local wind and weather, (*g*) minimal variation in the illumination of the satellite by the earth station and (*h*) high discrimination between orthogonally polarized signals. Most of the above design requirements are governed by the earth stations. *G/T* ratio (figure of merit) which was discussed in Eq. (2.19) of Chapter 2 and is re-written as -

$$\frac{C}{N}=\frac{P_T G_T G_R (\lambda/4\pi d)^2}{K T_S B} \qquad ...(11.1)$$

where for simplicity the additional losses L_A have not been taken into account. Here G_R/T_S represents the *G/T* ratio of the earth station. It is evident that *C/N* ratio is directly proportional to *G/T* and so most of the above eight important

stations.

Table 11.1. Characteristics of INTELSAT standard A, B and C earth stations.

Standard	*A*	*B*	*C*
Frequency (GHz)	6/4	6/4	14/11
Polarization	Circular	Circular	Linear
G/T dB K^{-1}	40.7	31.7	39 + 20 log (f/11.2)
Typical dish diameter (m)	30	11-13	19
Antenna midband receive gain (dB)	61	51.5	65
Antenna midband transmit gain (dB)	64	54.1	66.4
Main reflector rms surface tolerance (mm)	1.0	0.8	0.6
Typical LNA noise temperature (K)	40	40	120

1 GHz, antenna diameter
BW (E_1), 55-83 *dBW* (E_2),
34 dBK^{-1} (E_3). Standard *F*

has characteristics such as (6/4 GHz, antenna diameter = 4.5-5 m (F_1), 7.5-8 m (F_2), 9-10 m (F_3), *EIRP* = 63-91 *dBW* (F_1), 60-87 *dBW* (F_2), 59-86 *dBW* (F_3), *G/T* = 22.7 dBK^{-1} (F_1), 27 dBK^{-1} (F_2), 29 dBK^{-1} (F_3). Standard Z has characteristics (6/4 GHz, 14/11 GHz, *G/T* at 10° = 31.7-33.0 dBK^{-1} (for large), 24.5-26.9 dBK^{-1} (for small), 22.0 dBK^{-1} for TV/radio receive only.

It would be worthwhile to mention here that the diameter of the receiving antenna may be calculated either through Eq (11.1) or by the following expression

Here ½

$$D = 4R\left[\frac{LKTBFS/N}{P_T.G_T.\alpha}\right]^{1/2} \qquad ...(11.2)$$

where D is the diameter of the receiving antenna in metres, KT = product of Boltzmann constant and absolute temperature, and the unit is joules, R = range to satellite in meters, F = noise figures of receiver, S/N = signal to noise ratio, P_T = total power transmitted from satellite, G_T = gain of satellite antenna, B = signal bandwidth in Hz, L = polarisation, cable etc. losses, α = antenna efficiency.

Similarly, the earth station transmitter power may be calculated from

$$P = \frac{16R^2 LKTBFS/N}{D^2 G_T \alpha} \qquad ...(11.3)$$

This transmitter power ranges from a few tens of Watts to ten or twelve Kilowatts generated by vacuum tubes (klystrons or travelling wave tubes). Transmitters upto 400 KW are used in the deep-space network.

11.3. Earth Station Sub-Systems

(*a*) *Transmitter* : Here the signal to be transmitted is converted to the uplink frequency, with proper encoding and modulation. It is then amplified and directed to the appropriate polarization port of the antenna feed. In Fig. 1.2 the simple block of [illegible]

because of the tight specifications on out-of band emission, frequency stability and power control that are necessary to avoid interference with other channels and satellites. Further as transmitters are not manufactured in large scale so their cost is high. The cost increases with the increase in transmitted power which may vary from tens to thousands of watts.

Since earth stations require the transmission of microwave power, they use high power amplifiers (HPAs) such as travelling wave tubes and multi

transmitters.

Table 11.2. Brief Summary of HPAs' Characteristics

Amplifier Type	*Output Power*	*Bandwidth*	*Cost*
Klystron	500-5000 W	Small 40 MHz	Medium
Travelling Wave Tube (TWT)	100-2500 W	Large (500 MHz)	High
FET (6 GHz, 14 GHz)	5-50 W, 1-6 W	Large	High
Bipolar Transistor	Upto 50 W	Wide	High

Note : (1.6 GHz) to be used in maritime satellite communication system.

When there are several HPAs working their output may be combined through bandpass filters and circulators or by means of hybrids. Thus a modified version of earth's station transmitter may be as that given in Fig. 11.1. Here modulation is performed at 70MHz IF which is then upconverted. The configuration (arrangements) for HPAs to be employed depend on the number of carriers to be transmitted and whether these are FDM or TDM signals. The most common configuration employs one HPA for each transponder to be used. It must be remembered that reliability is of utmost importance in satellite communication and therefore the equipments in transmitters always employ some sort of redundancy configuration with automatic switch over in the event of some failure.

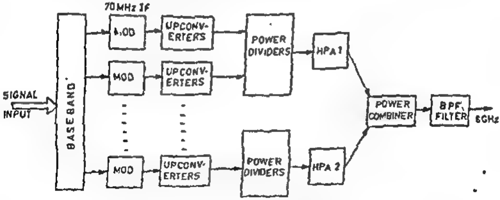


Fig. 11.1 Block Diagram of Transmitter

separate in the frequency domain as they are assigned to the uplink and

downlink bands, and in addition by means of orthogonal polarization. As shown in Fig. 1.1 (Chapter 1), diplexers are used to enhance the separation in the frequency domain.

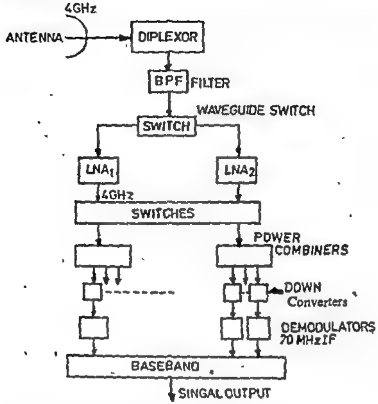


Fig. 11.2. Basic Block Diagram of Earth Station Receiver.

In Chapter 2, the noise [illegible]

These achieve noise temperatures in the range 50 to 120 K at 4 GHz and 120 to 300 K at 11 GHz. Table 11.3 gives a brief summary of the characteristics of various LNAs used in the receive part of earth station.

Table 11.3. Brief Summary of LNAs used in the Earth Station Receiver

Types of Amplifiers	*Frequency*	*Noise Temp.*	*Cost*	*Use*
Cryogenic parametric	4 GHz	15 K	High	Large station
Cooled parametric	4, 12 GHz	35,100 K	Medium	Standard *A* & *B*, Standard *C*.
Uncooled	4 GHz	50 K	Medium	Large domestic
Parametric	12 GHz	120 K	Medium	Eutelsat stations
Cooled FET	4 GHz	50 K	Low	Domestic
GaAs	12 GHz	130 K	Low	Domestic
Ambient	4 GHz	75 K	Low	Small domestic
FET GaAs	12 GHz	250 K	Low	Small Domestic

[illegible] configuration is used particularly for LNA.

[illegible] energy into a narrow beam to illuminate the satellite antenna in both the transmit and receive modes to provide the required uplink and downlink carrier power. The radiation pattern of antenna must not exhibit large sidelobe level otherwise there will be interference from unwanted signals and other satellites. The low noise temperature of antenna would allow to have a better C/N ratio. Similarly, the antenna must be easily steerable so that a tracking system may be employed to point the antenna beam accurately towards the satellite taking into account the satellite's drift in position. This would also allow pointing loss to be minimum.

[illegible] Though the horn antenna has a good performance, it is expensive and very bulky when high gain is needed. Hence they are not used for earth stations. The phased array antenna is of much use so long as it has small dimensions [illegible] phased array antennas are quite suitable. The reflector or dish antennas have

the advantages that they offer a wide range of gain values with affordable mechanical complexity. These reflector antennas are the paraboloid antenna (single parabolic reflector) with a focal point feed and the cassegrain antenna (Dual reflector) as already mentioned. There may be single offset reflector antenna also.

Fig. 11.3 illustrates a paraboloid antenna with a focal point feed. Here the feed's phase centre is located at the focal point of the paraboloid reflector. The feed is connected to HPA and LNA through an orthogonal mode transducer (OMT) which is usually a three port network. Thus when the antenna is transmitting the signal energy from the output of HPA is radiated at the focal point by the feed and illuminates the reflector that reflects and focusses the signal energy into a narrow beam. When the paraboloid is in the receive mode, it captures the signal energy and converges it on the focal point which is then received by the feed and routed to the input of LNA. This kind of paraboloid is easily steered and offers gain efficiency in the range of 50 to 60%. In case the antenna points to the satellite at a high elevation angle its focal point feed would face the ground. In such a situation the feed radiation will also spill over the edge of the reflector and illuminates the ground which may be as high as 290°K. This contributes a high antenna noise. This spill over may be reduced by tapering the aperture edge. The main problem with such antenna is that if

of aperture plane. Nevertheless the above paraboloid antenna with a focal point feed

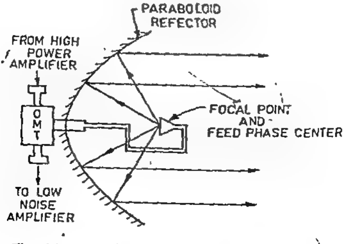


Fig. 11.3. Paraboloid Antenna with a Focal Point Feed.

It would be worthwhile to mention here that the size of earth station antenna affects allowable satellite spacing to avoid interfering with adjacent satellites. It is shown in Fig. 11.4. Considering the minimum allowable spacing, Fig. 11.4 shows that the earth station antenna would have to be at least 100 wagelengths in diameter. Thus holding the same beam width, the higher the carrier frequency the shorter the wavelength and the smaller the permissible antenna diameter. For example a 6 GHz uplink carrier has a wavelength of 5 cm and in such a case the antenna would have to be above 5 meters (or about 15 feet) in diameter. Similarly, for carrier frequency of 15 GHz (wavelength of 2 cms), antenna diameter would be 2 meter (or about 61/2 ft). For 30 GHz carrier frequency diameter reduces to 1 meter or about 3.3 ft which is quite suitable for mobile or home applications.

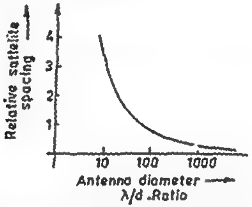


Fig. 11.4. Relationship between Antenna Diameter and Satellite Orbit Spacing.

common focal point of the main reflector and sub-reflector. The reflected

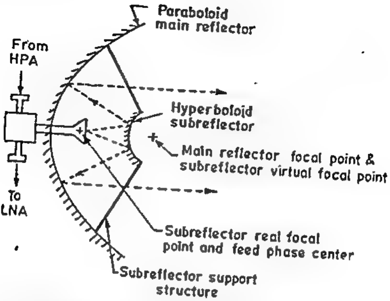


Fig. 11.5. Dual Reflector (Cassegrain) Arrangement.

Though the cassegrain antenna is more expensive than the simple reflector because of the addition of more elements such as subreflector and its support but it has several advantages such as low noise temperature, pointing accuracy and flexibility in feed design. Further here the spillover energy from the feed is directed toward the sky whose noise temperature is typically less than 30°K and thus the contribution to the antenna noise temperature is small as compared to paraboloid antenna. The feed is located near the vertex of the main reflector and so greater mechanical stability is achieved. This allows very accurate pointing of the antenna narrow beam. Oftenly alongwith the cassegrain antenna, beam waveguide feed system is used. This arrangement [illegible] losses in the [illegible]

When frequer [illegible]

quency reuse [illegible]

horizontal an[illegible] [illegible] ation for a Ku band operation. It would be worthwhile to mention here that a kind of reflector antenna termed as multi-beam Torus antenna has also been developed particularly by COMSAT laboratories which is capable of receiving simultaneously several satellites located in one section of the geostationary arc. This antenna is of small dimension such as a paraboloid antenna with diameter of 9.8 m with a gain of the order of 50 dB at 6/4 GHz and noise temperature of 30K for an elevation angle of 20°.

accurate program-track facility or a kind of autotrack system. A typical example of pointing accuracy is that if the antennas' 3 dB bandwidth is typically of 10 min. arc., it must be pointed with an accuracy of ± 1 min of arc in [illegible]

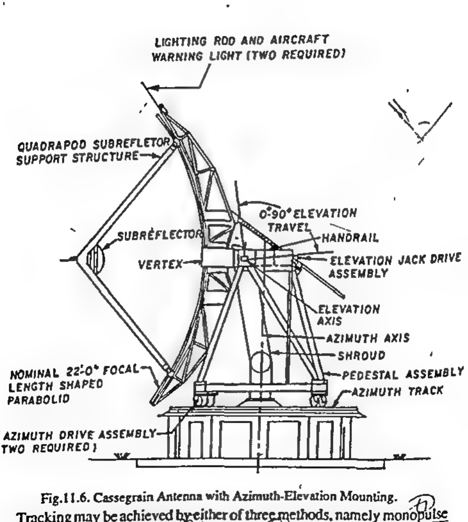


Fig.11.6. Cassegrain Antenna with Azimuth-Elevation Mounting.

Tracking may be achieved by either of three methods, namely monopulse or multi-horn tracking, conical scanning, step by step (also called step-track [illegible] order of 0.1 θ_{3dB}, it is complex and expensive and so it is not used. The most popular technique is step by step technique where a search for the maximum

reception of the received signal is done. This requires a continuous moving and checking of the beam. From the knowledge of main beam shape the true direction of the satellite is estimated and then the antenna is pointed in that direction. Such kind of tracking gives the systematic pointing error of the order of 0.2 θ_{3db}. Here the antenna is resetted by moving the sub-reflector. Sometimes the scintillations in the received signal may cause trouble in tracking and so continuous checking of scintillation amplitude is also needed.

11.4. Monitoring and Control

The importance of redundancy of some equipment in earth station such as HPA and LNA etc. has already been mentioned in the previous section. With this redundancy arrangement it is expected that when the on line equipment in the redundancy configuration fails, the standby (redundant) equipment has to automatically switch over and become the on line equipment. Infact this process of detecting critical failure modes and resolving all these failure modes by automatic switch over from the failed to the redundant system is termed *monitoring and control*. In a communication network using the communication satellite several earth stations alongwith a network control centre (NCC) are involved. Here this monitoring and control is quite important. This involves many levels such as rf terminal monitoring and control, remote monitoring and control of the earth station from the network control center *via* the satellite link with a backup terrestrial telephone line.

It is essential for monitoring and control system to have the capability to collect status data for classification, to convey status data to network operators, to interpret status data, to initiate fault isolations, to switch over redundant [illegible] the baseband equipment [illegible] to maintain surveillance [illegible]

11.5. Frequency Coordination

[illegible]

this coordination distance. The first step in the process is to determine the basic transmission loss L_b in decibels by the formula :

$$L_b = P_T + G_T + G_R - A_S - P_R \; dB \qquad ...(11.4)$$

where P_t is the transmitter power in dBW, G_t and G_r are the transmitter and [illegible]

[illegible] second step in the process involves the determination of distance corresponding to this L_b. Again the curves and equations to calculate this distance have been provided by CCIR. For this two modes of propogation have been considered by CCIR. These modes are mode *A* and mode *B* where mode *A* corresponds to great circle path mechanisms and mode *B* corresponds to scattering by rain. It must be remembered that rain may cause interference by [illegible] from the beam of a transmitting antenna into the aperture of

Infact A_s is calculated by the formula:

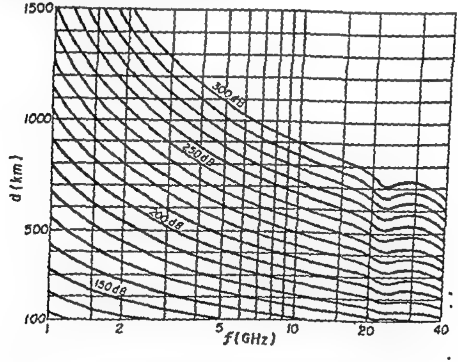


Fig. 11.7. CCIR Curve for Coordination Distance as a Function of Frequency and $(L_b - A_s)$ for Mode *A* Propagation.

$$A_s = 20 \operatorname{Log}_{10} (1 + 4.5\theta f^{0.5}) + \theta f^{0.33} \text{ for } \theta \geq 0^\circ$$

$$= 0 \qquad \text{for } \theta < 0^\circ \qquad \ldots(11.5)$$

Where θ is in degrees.

For mode *B* propagation the CCIR curve is shown in Fig. 11.8. Here the site sheilding is not considered (in rain scatter interference) and the CCIR curves for rain scatter coordination distance involve rainfall rate and frequency directly.

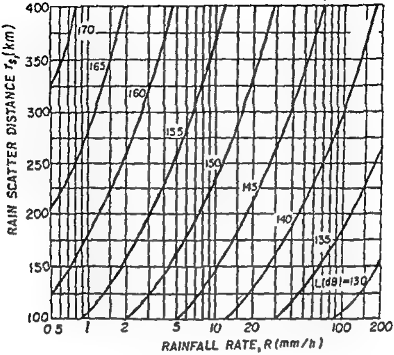


Fig. 11.8. Rain Scatter Distance as a Function of Basic Transmission loss and Rainfall rate at 4 GHz.

11.6. Small Earth Station

Basically small earth stations are defined as those which use antennas less than 60 wavelengths in diameter, corresponding to 5 m dishes at 4 GHz and 1.6 m dishes at 11 GHz; with gains below about 44 dB. For such a case front feed paraboloid reflector is being used. Cassegrain or dual reflector is not used as blockage losses are then very high. Though the symmetrical front end paraboloids are widely used for small earth station antennas, offset-fed antennas employing single and dual reflector configurations may also be used. The torus is also used to multibeam service purpose. Small earth stations do not need the expensive autotrack equipment, dual axis drivers and servo systems etc. for their antenna systems. Fixed pointing and small aperture antennas serve the purpose. Thus the small earth stations escape many of the problems encountered with large antennas and cost a small fraction of their large counterparts.

Small earth stations were developed basically for TVRO (television receive only) systems but these find use also in Telecommunication networking systems as shown in Fig. 11.9 or in other kind of services such as land mobile services or maritime services etc. as shown in Fig. 11.10. With the introduction of direct broadcast satellites (DBS) where satellite po increased, the cost of small earth station would as

case the antenna size could be further reduced to an extent of 2 to 6 ft. In such cases it would be proper to term the small earth station as *micro earth station.* The cost of such small earth stations are a few thousand US dollars.

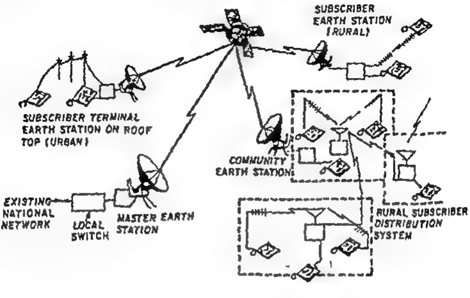


Fig. 11.9. Small Earth Stations in Telecommunication network Systems Operating in C/KU Bands.

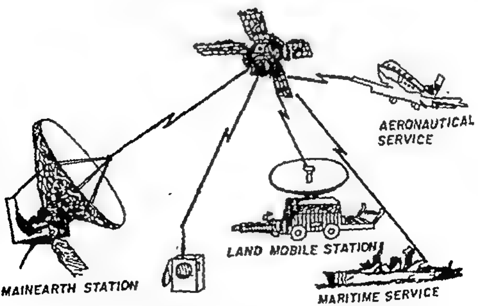
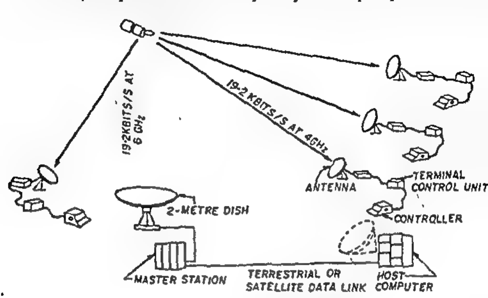


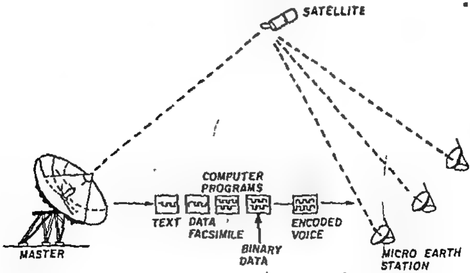
Fig. 11.10. Small Earth Stations in Various Telecommunication Services.

11.7. Very Small Aperture Terminals (VSATS)

These are a kind of small low cost earth stations which use different modulation/multiple access schemes especially for low speed packet data net-



(a)



(b)

Fig. 11.11. VSAT Application Modes
(a) For Data Transmission, (b) Star Topology.

works. These work mostly in C and KU band and use a very small antenna of diameter in range of 1.2 to 2.5 metre diameter. G/T ratio is usually less than 15 db/°K. LNA is uncooled GaAs FET of about 100°K. HPA is also a GaAs FET device providing power in 1 to 5 watt range. VSATs are also oftenly termed microearth stations and offer a low cost solution for thin route data communication between central host computers and a large number of remote sites. Thus VSATs generally employ a star topology with a large central or master station so that the antenna receive gain to noise (G/T) ratio of the VSATs and their cost is kept to a minimum. VSAT transmission takes place in the form as that shown in Fig. 11.11.

VSATs employ packet transmission with switching at the Master station to provide full virtual connectivity from one VSAT to any other VSAT by using a double satellite hop. Such networks are ideally suited for non-voice applications like computer and other forms of data communication. These employ spread spectrum multiple access (SSMA) and code division multiple access (CDMA) techniques. The data transmission rates are generally limited to 19.2 K bits at 4 GHz. They have advantages over terrestrial packet networks due to simpler flow and congestion control. Though sometimes there might be some delay problem. Voice transmission may also be done but it needs separate facilities which results into substantial increased costs.

mation, to small newspapers in remote locations and transmission of charts and documents (facsimile), including hand written information in various Indian languages.

11.8. Mobile and Transportable Earth Stations

lane. For mobile stations azimuth-elevation mountings are not preferred and ... tripod mounting is preferred.

One of the applications of the mobile and transport services is the shipping and for that the satellite INMARSAT (International Maritime Satellite Organisation) is used in communications for global shipping. It involves two kinds of earth stations, namely the coast earth station (CES) and the ship earth station. Infact CES is basically an earth station cum telephone exchange and the amount of software here is very high. It must be remembered that Intelsat ES has no software. There are two kinds of ship earth stations (SES) namely the standard A and standard C. Though the cost of SES is quite small compared to the cost of ship, the standard C type earth station is 10 times cheaper to standard A station and can be afforded even by fishing trawlers, road trucks and rail carriages.

Standard A ship earth station consists of two main parts, namely the above deck equipment (ADE) and the below deck equipment (BDE). The ADE consists of a parabolic antenna mounted on a stabilized platform, a diplexer to separate the transmitting and receiving signals, a solid state HPA for transmission, a LNA for reception, and a power supply for the amplifiers. The system is housed in a fibre glass radome for protection against weather. The diameter of the parabolic antenna depends on the SES standard type. The antenna mounting unit comprises a four axis stabilizing system with appropriate sensors and servo control. Other characteristics of ADE are given in Table 11.4. The BDE is housed either in a rack or in desk-top console. It comprises units to control the antenna, modulate the baseband frequency signals (voice, telex, facsimile etc.) into higher frequency signals, feed the antenna and viceversa. It also has controls, indicators and interface for telephone, teletype and other equipment.

Table 11.4 INMARSAT - *Standard A Earth Station Characteristics*

Antenna System	*Communication systems*
Diameter : typically 12 m	Transmit band : 1636.5-1645.0 MHz
Gain : typically around 23 dB	Receive band : 1535-1543.5 MHz
Beamwidth : typically around 10°	Receive G/T : $\geq$ -4dBK^{1}
Polarization : right hand circular transmit and receive	Transmit EIRP : 37dBW ± 1 dBW
	Capacity : single duplex telephony or telegraphy call at any time.

Standard C earth stations have $G/T = -19\ dBK^{-1}$. Standard C communications are message based. There was also a standard B type ship earth station with receive $G/T = -12\ dBK^{-1}$. Since standard B and standard A earth stations give similar operational characteristics and standard C is much cheaper than standard B so the standard C has been widely adopted. In such standard C type earth stations, communications are transmitted in bursts, at an information rate of 600 bps *via* satellite to CES. At the CES, the messages are stored and forwarded to their destinations in a form nominated by the sender, *i e.* the telex,

teletext, voice band data, electronic mail etc. *via* the national and international network. The procedure is reversed when a message is received by the terminal onboard. The standard *C* terminal is designed to operate at lower power through a non-stabilized omnidirectional antenna, anywhere within the INMARSAT satellite coverage.

In addition to the ship services, aeronautical communication services through the satellite system is also being done. Here the aeronautical ground earth station (GES) provides the link between the terrestrial system and the satellite network. They operate in C-band. The major components of a GES are the 12 metre diameter antenna, RF and IF equipment, and an Access control and signalling equipment (ACSE). The aircraft earth station (AES) falls into four categories depending on the equipment configuration and service capability. Class *I* AESS are fitted with low gain antennas and carry only medium rate data (300-600 bps). They support basic safety services. Class *II* AESS provide voice services only, and have high gain aircraft antennas. Class *III* AESS have high gain antenna and provide voice and data services. Class *IV* AESS combine classes *I* and *III*. They have low gain and high gain antennas, providing voice and data services. Besides the antennas, other important AESS units are : (*a*) the satellite data unit (SDU), performing most of the data handling, protocols, modulation and coding functions of the AES, (*b*) the radio frequency unit (RFU) performing frequency synthesis and up-and down conversions, and matching with SDU; and (*c*) the Beam Steering Unit (BSU) or alternatively antenna control unit (ACU) for mechanical antennas, to control Carborne antenna pointing.

11.9. Earth Stations in Near Future

The earth stations in coming years particularly in the beginning of the [illegible]

used for reflector antennas particularly for transportable/mobile systems. This will also reduce the cost of antenna. The same reflector with composite feed for CLS band working will be common. Array antennas and printed circuit antennas will be developed for various applications. High efficiency feeds with improved side lobe levels for closer spacing of satellite is also predicted.

[illegible]

(monolithic microwave integrated circuits) and VLSI's (very large scale integrated) at lower cost will reduce size and cost of up and down converters. Also the number of microwave circuits and IF amplifiers, filters etc. will be [illegible] n the frequency synthesized local oscillator working

at extended C-band, *Ku* and *Ka* bands. The frequency converters would be compact and are expected to be one third of the present size. Reliability shall also be improved as there would be less inter unit wiring and connection.

It is expected that major earth stations shall be using micro computer controlled sub-systems, monitored and operated remotely with advanced data logging facilities. This will avoid human errors in operation and data logging. DAMA (demand assignment multiple access) will be used by most of the small earth stations. Mobile satellite communication in *L/S* band are to be commonly used by small ships, trains, trucks and aeroplanes using INMARSAT or other satellites. With the development in electronic technology, the terminals are supposed to become cheaper, reliable and suitable to hostile weather conditions.

11.10. TVRO Systems (Television Receive Only Systems)

TVRO system have already been mentioned in the early part of this chapter. These are only the downlink side of satellite communications and consist of five major types of equipment, namely the dish (reflector), feed-horn/polarizer (antenna), low noise amplifier (LNA), receiver/downcoverter [illegible]

are cheaper than spherical ones and also allow the viewer to move from one satellite to another by using a polar mounting. Mesh dish is always preferable.

Signals from satellite are focussed by reflector onto the feed horn antenna which is situated at the focal point of the reflector dish. Some technique for polarity selection is also given. The LNA is a broadband mountable amplifier with the gain varying between 35 to 50 dB. LNAs are of GaAsFET and bipolar transistors. Sometimes LNA and downconverter are integrated into a single unit called low noise converter (LNC). The receiver part of TVRO consists of downconverter, IF amplifier/filter, demodulator and video/audio processor. Once the audio and video are properly processed, they may be viewed on a monitor.

11.11. Review Questions

1. What are the equipments that an earth station requires ? Discuss their design requirements.
2. What are the INTELSAT standards for earth stations ? Compare their relative major characteristics.
3. Explain with the block diagram the working of transmitter part of earth station. What are the HPA's being used here ? Compare their main characteristics.
4. Discuss the receiver's working in earth station with suitable block diagram. Also explain various LNAs used there.
5. Explain with suitable diagram the working of various antenna systems to be used in earth stations ? Give antenna requirements for large and small earth stations.
6. What is meant by tracking and pointing ? Explain its significance and technique as to how these are achieved ?

7. Explain the monitoring and control requirements for earth station equipments. Why is it necessary to have these ? Discuss.
8. Explain as to why is it necessary to have frequency coordination among earth stations themselves and earth station-terrestrial microwave links ? Discuss the techniques to achieve them.
9. Explain the operational characteristics and performance requirements of very small aperture terminals (VSATs), mobile and transportable earth stations.
10. What is a TVRO system ? Explain the units that a TVRO terminal should have. Discuss their operations.

11.12. Reference

In addition to the books mentioned in reference of Chapter I, reference is also made to the following as well :

1. Mohanty, Earth Station Technology, Tracking Satellites, Telematics India, Nov.-Dec., 1987, pp54-56.
2. Rao, Y.S. and Ghose, A.K., Voice Transmission Via Packets, Telematics India, June, 1988, pp46-48.
3. Rao, Y.S., Small Satcom. Terminals, ibid, pp. 49-50.
4. [illegible]
5. [illegible]
6. [illegible] N.J., 1988.
7. Computer and Communications, May, 1988, issue.
8. Rao, Y.S. and Ghose, A.K., Voice Transmission in Satellite Based Packet [illegible] ...un-
9. [illegible] ...ite

TWELVE

Special Purpose Communication Satellites

12.1. DBS (Direct Broadcast Satellite) System

Direct broadcast satellite system (DBS) also called as *broadcast satellite system* (BSS) have introduced revolutionary changes into domestic TV series. Here reception of TV signals from satellite is direct and is meant for the individual reception and community reception. It is operational in western countries since 1986 onwards and is far convenient and useful as compared to TVRO (TV receive only systems) both in terms of cost and handling. Various characteristics of DBS relative to other existing and some previous communication satellites are given in Table 12.1. DBS utilizes high power satellite (in future planned to be EIRP 200 dbW per channel)

Table 12.1. Brief Summary of DBS Characteristics Relative to Other Satellite Systems

Satellite	*Earth Station antenna diameter (meter)*	*Year of start*	*Satellite EIRP per transponder (dBW)*	*G/T (db/K)*	*Approximate cost $ US*
INTELSAT	30	INTELSAT 1 from 1965	INTELSAT VI 26.5 (global) 31.0 (hemi-beam)	40.7	6-8 millions
Domestic (US high channel capacity)	10-13	from 1972	32 (Conus)	32.4-34.2	2 millions
Domestic (US medium channel capacity)	5-7	1980	37-53 including that with spot beams	30.4-33.3	250,000
Domestic (US (TVRO)	4.5	from about 1976	32 (Conus)	32	3000 to 8000
Direct Broadcasting Satellite	0.75	1986 onwards	57-60	14	300

and regional coverage antennas. Most important feature of DBS system is that it allows earth station/terminal to be mounted in domestic area. The dish size is merely of the order of 0.4 to 0.75 metre with the cost of terminal being about $ 500 US. This has introduced a new kind of satellite communication/reception industry and the vendors are available with their DBS receiver and other equipment providing the capability of receiving 32 channels. Such universality of reception has provided benefits for both the public and programme suppliers. From the public interest standpoint more variety and diversity is desirable. For operators point of view, it has given big market with a singular transmission method.

In fact the idea of direct broadcasting of TV from a satellite was introduced even before 1986 with the existing communication satellites. Since these communication satellites had good EIRP per channel so these became defactor direct broadcast satellites with their signals received by large numbers of [illegible] However, at the moment it appears that every one is free to receive as many channels as he wishes and the mass production of high tech earth terminals must be successful for DBS to attain its goal of millions of direct to home receivers. Further the efficiency as high as 75% are now possible in production manufacturing of *small offset fed antennas. The advances of GaAsFET has* lowered the noise temperature (to the range of 2.8-3.2 dB) of low cost mass producible 12 GHz receiver front end. All these have boosted the application of DBS system.

Configuration wise a direct broadcasting satellite consists of a television repeater station in geostationary orbit, a ground station that transmits program [illegible] minal antenna (dish) is of 2 ft. (0.6m) in diameter. Because of this reduction [illegible] for equipment and installation is reduced [illegible] given [illegible] ven in Fig. 12.2. The overall components in DBS are exhibited in Fig. 12.3.

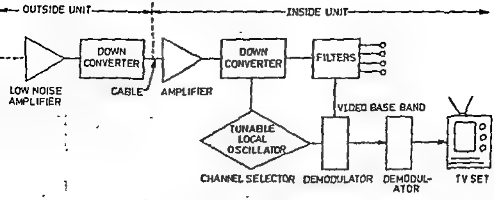


Fig. 12.1. Block Diagram of DBS System.

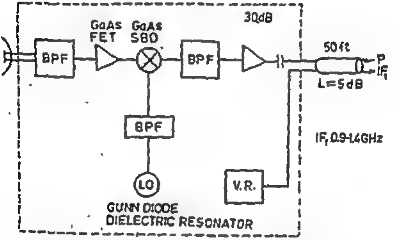


Fig 12.2. Details of outdoor unit of a DBS home receiver.

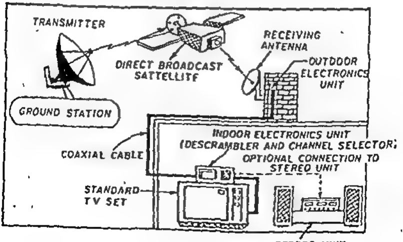


Fig. 12.3. Link Components in DBS System.

Table 12.2. DBS Frequencies Allocated to India

Ch.No.	Frequency	Orb.Lo	EIRP	Ch.No.	Frequency	ORb.Lo.	EIRP
1	11727.48	56° 68°	63.1 63.3	13	11957.64	56° 68°	63.3 63.5
2	11746.66	56° 68°	63.9 63.3	14	11976.82	56° 68°	63.7 64.1
3	11765.84	56° 68°	63.3 63.4	15	11996.00	56° 68°	63.5 63.6
4	11785.02	56° 68°	63.6 63.7	16	12015.18	56° 68°	63.8 65.5
5	11804.2	56° 68°	63.1 63.4	17	12034.36	56° 68°	64.3 63.6
6	11823.38	56° 68°	63.6 64.0	18	12053.54	56° 68°	63.8 63.8
7	11842.56	56° 68° 68°	63.4 63.5 63.5	19	12072.72	56° 68°	64.3 63.6
8	11861.74	56° 68°	63.7 63.7	20	12091.90	56° 68°	63.8 63.8
9	11880.92	56° 68°	63.2 63.5	21	12111.08	56° 68°	64.4 63.7
10	11900.10	56° 68°	63.6 64.0	22	12130.26	56° 68°	63.8 63.8
11	11919.28	56° 68°	63.5 63.5	23	12149.44	56° 68°	64.4 63.7
12	11938.46	56° 68°	63.8 63.8	24	12168.62	56° 68°	63.9 63.9

that 500 Watts transmitter output power per channel is needed for DBS satellite

0.9 m and a power flux density of 103 dBW/m^2 as per WARC 1970 specifications. With this specification it is evaluated that for a receiver of noise figure of 7 dB, the required input signal power to produce an SNR of 40 dB, would be around −104dBW. An allowance of 10 dB is made to account for losses in the aerial feed to the receiver and any inaccuracies in aerial positioning. Thus assuming an efficiency of 50% for the 0.9 m dia. dish (*i.e.* effective area ≈ 0.3 m^2), one would need an output power of − 104 + 1 = − 103 dBW from the dish.

This much of power is equivalent to power flux density (pfd) of -98 dBW/m^2. This corresponds to the required satellite power of $P = (pfd) \times (4\pi d^2)$ watts = 3MW (where d is the distance between geostationary satellite and dish = 35779 km). With the inclusion of mean excess path loss of 0.5 dB, it becomes 3.5 MW which infact is the required effective isotropic radiated power (EIRP). Since EIRP is related to power supplied to the antenna of satellite, P_s and its gain G_s *i.e.* $P_s = (EIRP / G_s)$ so at 12 GHz the parabolic dish providing gain of 45 dB and beamwidth of 0.5°, the transmitter power would lie between 150-200 watts. Since solar cells derate at a rate of 30% during its 7 year life time so around 600 watts of output solar power is needed for each transponder in the satellite. Since the area of solar panels is directly proportional to the output power, the number of transponders is basically limited by the available cargo space in a launch vehicle. Typically a 3 metre space is available in the Ariane and 5 metre space is available aboard the space shuttle. To overcome the problem of sun's shadow during midnight, WARC planners have suggested that a DBS satellite be positioned slightly westward of its intended coverage area.

From India point of view at the moment there is no plan of DBS system in near future, particularly because of the planning already being done over a decade ago for the present range of Indian national communication satellite system (INSAT series). Further, the emphasis has been on satellite telecommunication services rather than TV broadcasting services. Technical wise the power radiated by these INSAT series is quite small and are not significant for DBS services. However, India may do so at the end of this century as already two orbital locations have been allotted [illegible]

satellite at 4 different frequencies thus allowing accommodation of 48 total programmes at a time. For uplink frequency India is allotted 14.5-14.8 GHz band (in addition to the 17.3-18.1 GHz).

It would be worthwhile to mention here that now DBS is becoming quite important worldwide. Table 12.3 gives some of the future launch schedule of European North American and Japan DBS systems. Though the purpose of DBS might vary from countries to countries, in some countries satellite

broadcasting is intended to increase the number of TV programmes while in other countries it is intended to increase or expand the areas of TV signal reception.

Table 12.3. Some Future DBS System of the World.

Satellite	*Date*	*Country*
TVSAT 1	May, 1989	West Germany
TDF 1	Oct., 1988	France
ASTRA 1	Nov., 1988	Luxemburg
TELE-X	Feb., 1989	Northern Europe
OLYMPUS	Jan. 1989	ESA
TDF 2	Dec. 1989	France
BSB	Oct., 1989	Great Britain
EUTELSAT 2A	Jan. 1990	EUTELSAT
EUTELSAT 2B	Mar, 1990	EUTELSAT
EUTELSAT 2C	Sept. 1990	EUTELSAT
HS-601	1992	USA HUGHES
ECHOSTAR	1991-1992	Echostar Sat. Corp. USA.
CONTINENTAL	1990	Continental Sat Corp USA
USSB (RCA)		United States Satellite Broadcasting, USA.
DOMINION HS-394		Dominion Video Satellite, USA
ACC (RCA)		Advanced Communication Corp.
BS-3		Japan.

12.2. INMARSAT

It is an international organisation that controls satellite systems for communication between ships and coast so that emergency life saving services may be provided to the distressed people/ships. INMARSAT is accronym of [illegible]

INMARSAT, countries are drawn from East and West, North and South, the rich industrialized nations and the not so rich developing nations. It may, however, be noted that USA maintains its lead in INMARSAT by holding

maximum share in it. Table 12.4 indicates INMARSAT's significant share holders. Signatories from member countries own INMARSAT, they contribute to the costs of the organisation and develop its policies. Infact maritime satellite communication via INMARSAT are available to all ships without discrimination on the basis of nationality.

Table 12.4 INMARSAT's Significant Share Holders

Country	Share	Country	Share	Country	Share
USA	28.6	Japan	8.7	USSR	2.3
U.K.	17.6	France	2.5	Netherlands	2.3
Norway	16.0	Singapore	2.4	Canada	2.2
		India (20th position)	0.44		

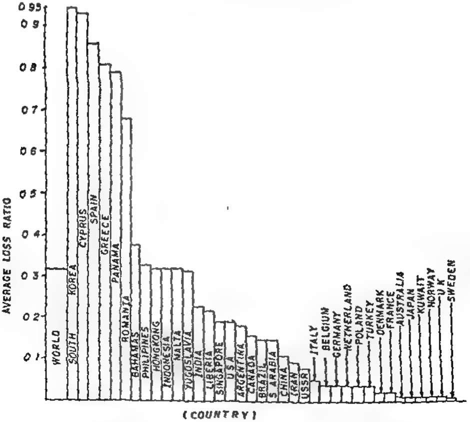


Fig. 12.4. Fleets by flag of 2 million gross tons and over (in 1982) Average loss ratio (1982-1986). All countries figures relate to increase in tonnage afloat except (**) figures which denote decrease in tonnage afloat.

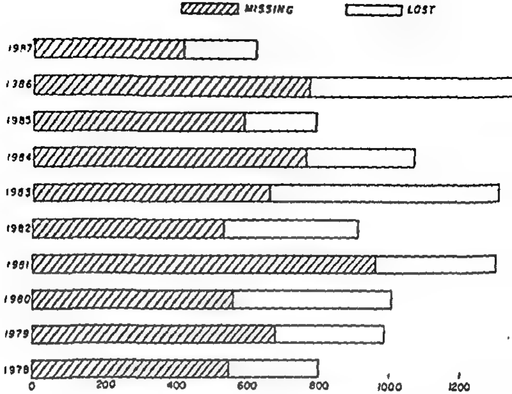


Fig. 12.5. Analysis of total number of lives lost or missing since 1978 by Year.

The importance of international maritime (shipping) communication may well be understood from Figs. 12.4 and 12.5 which indicate the numbers of ships and lines lost in some past years. The INMARSAT is therefore to exist

communication. It is for services exclusively for peaceful purposes. At present there are almost 5000 ships, boats and offshore rigs that are fitted with INMARSAT user equipments. There are 13 manufacturers of the special licensed ship terminals.

Finance of INMARSAT is met by the contributions of signatories. Sig-

sufficient revenues for the organisation to cover its operating maintenance and

Registered Private Operating Agencies offering maritime satellite communications via INMARSAT. Example of user charges are as follows. The US coast earth stations located as Southbury, Connecticut and Santa Paula, California charge \$ 4 per minute for telephone and \$ 10 per minute for telephone with a \$ 2 minimum charge for telex and a \$ 5 minimum for a phone call. In addition to these charges the user has to pay any extra long distance rates charged by the carrier for handling call between CES and telephone ES.

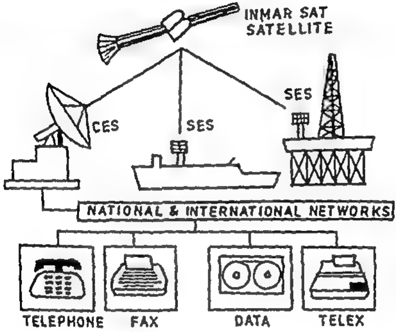
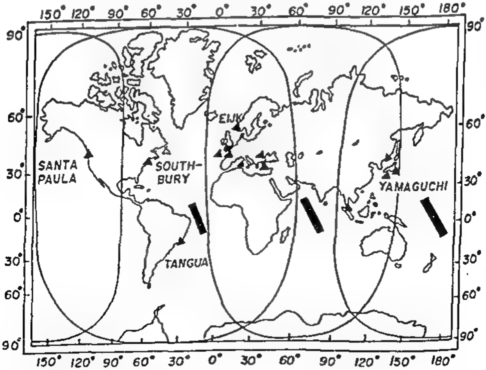


Fig. 12 6. Areas of Working of INMARSAT.

Area of working of INMARSAT is shown in Fig. 12.6. This involves national and international networks covering telephone, facsimile, computer, telex etc. Use of the services available via INMARSAT offers (*a*) direct communication between vessels, rigs and international telephone and telex network, (*b*) reduced response time, (*c*) automatic data transmission, (*d*) increased efficiency, (*e*) reduced operating costs and (*f*) enhanced safety

Table 12.5 INMARSAT Satellites

Region	*Satellite*	*Orbit*	*Date of operation*	*Status*	*Leased from*	*Telephony channels*
Atlantic (AOR)	Marecs-B_2	26°W	9.11.84	Operational	ESA	80
	Intelsat V-MCSB	18.5° W	19.5.83	Spare	INTELSAT	50
					COMSAT	10
	Marisat-F_1	15°W	19.2.76	Spare	general	
Indian (IOR)	Intelsat V (MCS-A)	63°E	28 9.82	Operational	INTELSAT	50
	Intelsat V (MCB-C)	60°E	19.10 83	Spare	INTELSAT	50
	Marisat F_2	72.5°E	14.10.76	Spare	Comsat general	10
Pacific (POR)	Intelsat V (MCS-D)	180°E	4.3 84	Operational	Intelsat	50
	Marecs-A	178°E	20.12.81	Spare	ESA	60
	Marisat-F_3	176.5°E	9.6 76	Spare	Comsat general	10



KEY. • Operation Control Centre, ▲ Coast Earth Stations of the INMARSAT System; ▬ Operational Satellites.

Fig. 12.7. INMARSAT coverage area.

Fig. 12.6. also indicates various essential components of INMARSAT system. These are three in numbers, namely (*i*) the INMARSAT space segment consisting of the satellites and ground support facilities which are planned by INMARSAT and funded by its signatories, (*ii*) the coast earth stations (CES) which provide an interface between the space segment and the national and international fixed telecommunication networks and are funded generally by signatories, and (*iii*) the ship earth station (SES) which are the satellite communications terminals purchased or leased by individual ship owners/operators. Frequency range of operation of INMARSAT satellites is in L band, 1535-1542.5 MHz for satellite to mobile terminal and 1636.5-1644 MHz for mobile terminal to satellite. Satellite transmissions to and from CES are in the C band at 4.6 GHz. East Intelsat satellite has a capacity in the L band of about 30 telephone voice channels while each Marecs and Marisat channel has a capacity of about 50 and 10 channels respectively. An additional 1 MHz from ship-to-satellite has been allocated between 1645.5-1646.5 MHz and from satellite to ship, between 1544-1545 MHz exclusively for distress and safety purposes. It is essential that all of the user equipment must be type accepted by INMARSAT and each individual set must go through a battery of on-air commissioning tests before it can be placed into service.

Calls to or from a ship terminal (whether on board a ship or ashore) are routed *via* satellite to a coast earth station where they are patched directly into the international switched telecommunication networks. No special equipment, other than a standard telephone or telex machine is necessary for the shoreside user to initiate or receive a call through the system. It must be remembered that present day INMARSAT system equipment are called 2nd generation equipment. In very near future three higher capacity global beam satellites carrying more than 200 channels being manufactured by an international consortium headed by British Aerospace will be launched by Ariane and McDonnel Douglas Delta Rocket. There is also a plan to deploy some more satellites which would employ multiple spot beams that would concentrate satellite capacity and help in use of smaller antennas which would create a mass customer market.

A discussion about both the coastal as well as ship earth station has already been made in Section 11.8. Table 12.6 lists the CES working round the globe. In addition to these 20 INMARSAT CES operating in 13 countries in the three ocean regions, 19 more are planned or are under construction including the Indian CES at Arvi, 200 Kms. from Bombay, all scheduled for services in 1989 or early 1990. Services include Telex, telephone, facsimile at 2400 bps and high speed data at 56 kbps. Though at the moment there are 3 kinds of main ship earth stations, namely the standards A, B and C but in the coming years INMARSAT shall be introducing a new standard ship earth station systems in which the telephone signal transmission channels currently operated by companded FM would be digitized. These digitized transmission systems will provide a saving of limited satellite power and capability to offer a wide variety of new services and will allow for low cost and stable shipborne equipment.

Table 12.6. INMARSAT CESs

Atlantic Ocean Region:	*Indian Ocean Region:*
Southbury - USA	Yamaguchi - Japan, Odessa - USSR
Goonhilly - UK	Eik - Norway, Psary - Poland
Tangua - Brazil	Thermopylae - Greece
Umm-al-Aish - Kuwait	Nakhodka - USSR
Odasse - USSR	Jeddah - Saudi Arabia.
Fucino - Italy	*Pacific Ocean Region :*
Plemeur Bodou - France	Ibraraki - Japan, Nakhodka - USSR
Psary - Poland	Santa Paula - USA
Maadi - Egypt	Santosa - Singapore.

As aleady mentioned in previous chapter (Section 11.8) a CES is an earth station alongwith a telephone exchange through which national, international telephone, telex and data networks are connected to the maritime user. Each CES has a parabolic antenna reflector of the size between 10 and 13 meters diameter for 6/4 GHz communications with the satellite. Same reflector or another between 1.5 and 3 diameter controls the test transmission in the 1.6 GHz band and monitors satellite to ship signals in the 1.5 GHz band. The tracking system keeps the antenna precisely pointed towards the satellite. RF and other equipment process the signals received from the satellite. Through acesss control and signalling equipment relying on complex computer software a link is established between the INMARSAT system and the national/international network. The CES provides two major categories of services, (*a*) public correspondence and (*b*) safety related services.

[illegible] Distress and [illegible] within VHF range, area A_2 within MF range and area A_3 within [illegible] lar regions are not covered [illegible] he ships through distress signals. The distress signals would be received by a shore-based Rescue Coordination Centre (RCC) coordinating rescue operations which in turn alerts ships through Enhanced Group Call (EGC). This EGC using the standard *C* system is supposed to provide two kinds of services the *safety net and fleenet* to ships round the clock. With safety net a standard *C* terminal will receive and record weather navigation distress and other emergency information

relevant to vessels operating in, or approaching an area. Fleenet is intended for commercial information news, sports, commodity prices, currency notes, stock exchanges, reports etc.

INMARSAT has also the system called *Distress Message Generator* that can be built in Standard *A* or *C* SES which is good for increasing the maritime safety. This device is capable of transmitting automatically distress messages including SES identity, position, nature of distress, course and speed of vessels, data/time of activation and the form of help required. In the worst case of ship sinking, the device will remain afloat and keep on transmitting data. EPIRB (emergency position indicating radio beacon) is another kind of safety device that has also been used to work with INMARSAT. This device is used when the ship is sinking or in distress or the seamen are scattered in the sea. The device works automatically and infact when it floats emits radio signals telling its identity location which are picked up by the satellite and related to CES. There is also another future planning in INMARSAT to introduce multichannel SES that will be used by very big ships having standard *A* antenna. These will simultaneously work on four telephone or telex channels and will also provide a voice broadcast service allowing facsimile or voice to be broadcast.

INMARSAT has opened its system for land-based users for long range communications in remote areas of the world. The organisation INMARSAT grants licenses for land based terminals on a case by case basis, the chief criterion being a requirement for high quality communications where other facilities aren't available. Also, permission from the country in which the terminal is to be used must be obtained prior to INMARSAT commissioning.

As of Sept. 1, 1986 there were more than 269 land based terminals in service according to INMARSAT's published figures. A large percentage of these are located in parts of Africa, Asia or other third world nations where there is no public telephone network or other commercially available communication service. Typical customers for land based satellite communications include disaster relief agencies, law enforcement, remote mining or construction sites, oil wells, land survey teams and newscasting. The INMARSAT system offers important advantages for land based users, including cost effectiveness, worldwide coverage, support of data/fax communications, ease of use and of deployment, and also security. With INMARSAT service is paid for only as it is used. There are no fixed charges other than the initial cost of buying the satellite terminal. The user doesn't have to pay for a leased satellite transponder or dedicated lines and there are no monthly minimums for system usage. This makes the system especially attractive to lower volume or those needing temporary communication satellites. The capital cost of buying and deploying the system are minimal. A transportable INMARSAT terminal costs less than \$ 50,000 and no dedicated equipment is needed at the other end of the line.

In future INMARSAT is going to be utilised to provide services to mobile users both on land and air too. For such case, the name of INMARSAT most probably be changed because then it would provide services to long distance and remote area travellers on land trucks, buses, trains, vacationers, explorers and adventurers and the worldwide aviation community for air traffic control, airline operations and passenger communications. Some developed countries have already developed land mobile satellite services called as *Radio Determination Satellite Service* (RDSS) that aims at providing location and short digital messaging service. One example is that of Geostar Corporation of USA's RDSS. Vsats are another development in the area.

Recently NASA shall be introducing a modified ship earth station (SES) to be carried by a high altitude balloon. This SES infact will be carried out on a supernova long duration space balloon flight planned by the US space agency. The balloon will carry equipment for observations for a large supernova visible from the southern hemisphere and will use the Satcom terminal for transmission of data throughout its flight. The balloon will travel from Australia to Brazil in journey lasting between 7 to 10 days at a height of 40 km taking in the edge of Space.

[illegible]

in phases. Phase I will work towards evolving passive, active and hybrid position-determining technique, compatible with the US Group Position System (GPS) and USSR's Glonass. Phase II will involve the implementation of these techniques with detailed block diagrams and the writing of software protocol.

12.3. INTELSAT

It is Washington, DC, USA based International Telecommunication Satellite Organisation that provides telecommunication services to its member countries throughout the world by means of satellite systems owned by it. Its first satellite was launched in 1965 (termed *early bird*). The telecommunications services include not only just telephone but also the TV, digital transmissions services, telegraphy, telex, computer to computer, video conferencing, video text etc. Infact INTELSAT system handles these services through more than 700 earth stations spread across more than 155 countries. These countries range from rich to developing ones, east to west and north to south.

As per 1987 data there were a total of 113 member countries of INTELSAT organisations, among them, 105 countries have operational earth stations. The eight member countries without earth stations were Afghanistan, Chad, Finland, Liechlenstein, Luxembourg, Monaco, Vatican city state and Vietnam. The 38 non-member stations which were capable of accessing INTELSAT satellites included Antigua, Burma, Cuba, Korea, (DDR), Poland, USSR. The 17 dependent special areas with INTELSAT operational stations [illegible] the Falkland islands, French polynesia, Hongkong. Macao and the

US territories of Guam and Palau. Out of 700 earth station antennas in the Intelsat system, some 330 are for domestic purposes. Table 12.7 indicates such antennas for both international and domestic use. Special applications in Table 12.7 refer to training, experimental and nonoperational purposes.

Table 12.7 Operational Antennas by Standard

	A	*B*	*C*	*D*	*E*	*F*	*G*	*M*	*N*	*Z*
International	211	93	10	1	31	7	4	0	11	0
Domestic	3	3	0	2	0	0	0	0	2	311
Special	0	0	0	0	2	0	0	6	0	0
Total	214	96	10	3	33	7	4	6	16	311

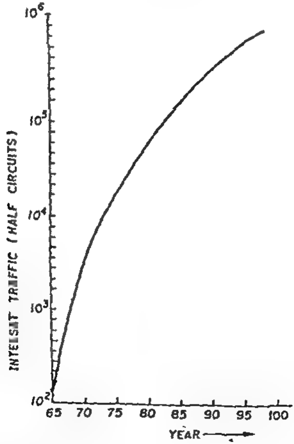


Fig. 12.8. Intelsat International Traffic Growth.

The INTELSAT traffic has been [illegible]

modulation techniques to provide diverse services globally. As per data available in 1987, in Atlantic Ocean there are 51063 half circuits whereas in Indian and Pacific Ocean there are 21104 and 14141 half circuits respectively.

Table 12.8 Satellite Equipment Sales in Million of Dollars

Equipment	*1977*	*1986*	*1991*	*1995*
Satellite Platforms	122	325	425	500
Space Antennas	39	230	350	475
Transponders	99	520	800	1070
Other Space Equipment	10	50	75	105
Receive Only Earth Stations	18	785	1700	2775
Ground Antennas	21	295	600	1100
Transmitters/Receivers	33	485	1050	2050
Tracking and Control Equipment	22	345	675	1225
Other Ground Equipment	9	115	250	500
Total	373	3150	5925	9800

The increase in worldwide satellite communication facilities has increased the world market for communication satellite equipment. A US report says that even the US market for communication satellite equipment is projected to increase 13.4% per year through 1995, to $ 9.8 billion. The report says that through the mid 1990's growth for the space segment of the market will lag that of ground equipment continuing a long standing trend. And by the 1990's long distance common carrier telecommunications probably will be replaced by broadcast communications as the largest single application for the communications satellite equipment. Table 12.8 indicates the above projected US market of 1955s.

There are 6 INTELSAT satellite systems which have been launched from time to time. These are probably known as INTELSAT I, II, III, IV, V & VI. Table 12.9 indicates in brief the characteristics and operational activities of these satellites. It must be remembered that under one INTELSAT system [illegible] of the global cov-

[illegible]

and discu: [illegible]
Board of [illegible]
regional [illegible]
hnical and performance characteristics that earth stations meet in order to
icipate in the Intelsat system.

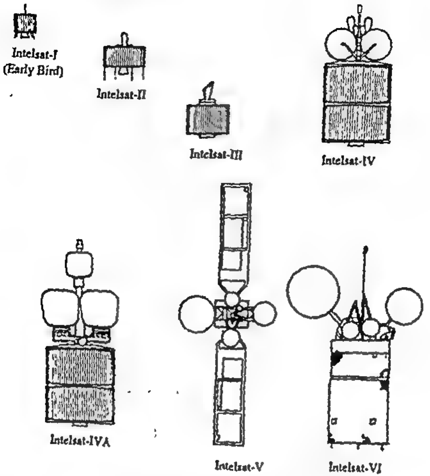


Fig. 12.9. Configurations of various Intelsat Systems.

From Table 12.9 it is evident that with the new generation Intelsat satellite systems the telecommunication capabilities have increased tremendously. It can be seen that the Intelsat I, the world's first commercial communication satellite was launched in 1965 which was designed to operate for 1.5 years and 480 half circuits. By contrast intelsat VI is designed to operate for 10 years and provide upto 80,000 half circuits. This tremendous jump in capability over six generations of Intelsat satellites is due largely to the continuing growth of launcher capabilities and the continuing refinement of sophisticated shaped-beam satellite antennas. Intelsat designs also incorporate advances in microwave integrated circuits, satellite propulsion, solar cells, and batteries. Intelsat VI introduces a microprocessor based control system and the satellite-controlled communication switching.

Table 12.9. Brief Operational characteristics of Intelsat Systems

Characteristics	*Intelsat I*	*Intelsat II*	*Intelsat III*	*Intelsat IV*	*Intelsat IVA*	*Intelsat V*	*Intelsat VI*
Launch year	1965	1967	1968	1971	1975	1980	1987
Dimensions	0.71 m dia x 0.59 m high	1.42 m dia x 0.67 m high	1.42 m dia x 1.98 m high	2.38 m dia x 7.01 m high	2.38 m dia x 7.01 m high	15.27 m accros solar sails x 6.71 m high	3.6 m dia x 11.7 m high
On orbit weight	34 kg	76 kg	152 kg	595 kg	786 kg	1020 kg	1800 kg
End of life primary power	46 W	85 W	125 W	569 W	708 W	1220 W	2100 W
Total bandwidth	50 MHz	130 MHz	360 MHz	450 MHz	720 MHz	2250 MHz	3360 MHz
National capacity two way telephone circuits	240	240	1500	5000	11000 plus 2 TV channels	24000 plus 2 TV channels	33000 plus 2 TV channels
Design life time	1.5 years	3 years	5 years	7 years	7 years	10 years	10 years
Attitude Control	Spin	Spin	Dual Spin	Dual Spin	Dual Spin	3 axis	Dual Spin
Transponder Nos	2	1	2	12	20	27	48
Coverage	North Hemisphere	Global	Global	Global & Spot beams	Global & Spot beams	Global, Regional and Spot beams	Global, regional & Spot beams
eirp (dbW)	11.5	15.5	23	22.5 (global) 33.7 (spot beam)	22 (global) 26 (hemisphere) 29 (spot beam)	23.5 (global) 29 (hemisphere) 29 (zonal) 41-44(spot beam)	26.5 (global) 31.0 (hemisphere) 31.0 (zonal) 41-44 (spot beam)

Characteristics	Intelsat I	Intelsat II	Intelsat III	Intelsat IV	Intelsat IVA	Intelsat V	Intelsat VI
Type of vehicle, number of satellites launched	Thurst Augumented Delta/-there was only 1 satellite launched in this series	Improved thrust Augumented Delta/3 satellites successfully launched and 1 launched failure	Improved thrust Augumented long-tank Delta/5 satellites successfully launched and 3 launched failures	Atlas-centaur launch vehicle/7 satellites successfully launched and 1 launch failure	Atlas-centaur launch vehicle/5 out of 6 satelites in this series successfully launched	Initially both Atlas-centaur and ESA's Ariane for 9 satellites with one failure further gradually 15 Satellites were launched	—
Spacecraft	$ 3 6 M	$ 3 5 M	$ 4.5 M	$ 14 M	$ 18 M	$ 25 M	$ 140 (First five Satellites)
Launch Cost	$ 4 6 M	$ 4 6 M	$ 6 0 M	$ 20 M	$ 20 M	$ 23 M	
Cost per telephone circuit year	$ 23000	$ 11000	$ 1600	$ 810	$ 494	$ 200	
Contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Hughes

The intelsat V series of satellites launched 8 years ago has long surpassed its design life. The first satellite in this series is expected to remain in full use till 1992. There is enough fuel on board to sustain the bird till 1989, but an inclined orbit could extend its life to 1992. There is no sign that intelsat V.s life would be extended. The 11 satellites in this series transmit more than a billion telephone calls each year according to their manufacturer, Ford Aerospace & Communication Corporation. Ford has built 15 intelsat Vs *representing the largest order ever for a single series of communication satellites*. Now intelsat has invited manufacturers to bid on a new series of satellites designed to be region responsive. The first 2 spacecrafts of the new series will be launched in 1992 or 1993 abroad Ariane or Titan III rockets. Intelsat proposes to buy upto 9 of the new satellites. The first 2 satellites will serve the Pacific region, but the others may be deployed over other ocean regions. The 'birds' will be high powered to allow the use of smaller antennas, and each will carry 36 transponders – 16C band at 72 MHz ; 10 C band at 36 MHz, 6kU band at 72 MHz and 4 more Ku band at 112 MHz.

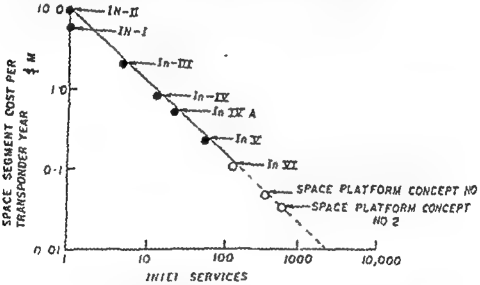


Fig. 12.10. Economy of Scale in Communications space craft of (Past and Present) Intelsat series.

It is worthwhile to mention here that as the technology developed there was economy in the space segment cost per transponder year. Table 12.6 [illegible]

positive trend. The main reason responsible for this is the decrease in micro electronics circuitory cost though the launch cost may be higher. The life

extension to orbit ...

... over the next ten years. The ... should stimulate a ... assumes that 80% of all traffic will be digital by 1996. The most rapid transition model however, place the level below 50%. A range of digital traffic that could be as high as 80% or as low as 45% is a wideband. Actual Intelsat planning will probably assume in between figure of 65%.

12.4. Data Broadcast Satellite (VSATs)

A reference to Vsat (very small separate terminal) is already made in Section 11.7. Infact such a development of technology in satellite communication has allowed data and voice ...

... very small aperture terminal among ... and use of satellite communications ... panies that want to connect operations across distances that make microwave networks difficult and expensive. Such small station services can be easily installed at customer locations to provide voice, data and video. These smaller antennas or stations generally seven to eight feet in ... room, are easier to install ... tribute toward the lower ins... themselves have contribut... small stations a very cost effective solution. These small station networks are proving to be more reliable with higher performance than traditional terrestrial services. They are becoming increasingly popular because they offer a single vendor solution instead of the problems of working with several terrestrial service providers.

Though the use of a VSAT depends upon the specific application but in general a company for ... lower initial costs and ... both in terms of services are rising in ... unpredictable manner and their installation often produces significant, random delays. A VSAT network solution will allow to eliminate these delays, stabilize costs and still be able to ... reconfigure the network in ... at new c... more ef... provid... compa... The VSAT networks ... position. Finally these ... should also increase the flexibility of ... condensing se...

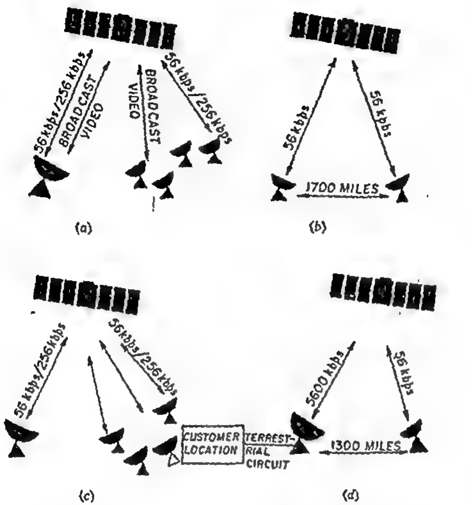


Fig. 12.11. Some Typical Application Services of Data Broadcast Satellite and VSATs.

(a) Intelligent Service (b) 56 kbps Transmission Between two Customer Locations (c) Intelligent Service (d) 56 kbps Between Customer premise and a National Network

Fig. 12.11 indicates some of the typical application areas of VSAT and Data Broadcast Satellite. Fig. 12.11(a) is an example of Intelligent service which has an application such as in a retail data network using interactive transaction processing for credit card verification, inventory control and broadcast video for branch store training, [illegible]

Fig. 12.11(c) indicates once again the example of an intelligent service. Typical application area is that of a corporate data network using interactive transaction processing for inventory, payroll and other administrative requirements.

interspersed with large data file transfers. Finally in Fig. 12.11.(*d*) service of 56 kbps between customer premise and the company's national network is shown. Typical application is that of bulk data transfers between a company's MIS center and corporate headquarters. Since earth station could not be located on site, so customer interfaces with the company's national network.

From above example it is clear that VSAT data networks create and manage transmission media. This is done by performing five basic functions, namely transmission, multiplexing, bandwidth allocations, protocol, handling and network management. Transmission refers to the ability to establish a physical channel using the VSAT microwave radio and satellite modem equipment along with the satellite itself. Multiplexing is the task of aggregating streams of data from multiple sources for transmission over the network. Normally time division multiplexing is employed. Bandwidth allocation involves the ability to manage the transmission channel as a resource and allocate it to VSAT in an intelligent manner so as to meet their instantaneous needs. Protocol handling refers to the ability to establish and maintain multiple communication sessions between computers and various other devices. Network management involves collection of information about the network, analysis, determination of action, and presentation of information to allow an operator to effectively control the network.

VSAT evaluated as a wide area data communication network fit almost any application currently served by telephone lines and an array of devices such as modems and multiplexers. VSAT can be used also with value added network (VAN). Infact a VSATVAN is particularly well suited to providing network management services that are expensive or difficult to obtain from conventional data networks. Advantages include support, network flexibility and reliability, network control reporting, ease of installation and cost savings. VSATs and VANs are a cost sompetitive reliable satellite data communication service ideal for networks with as few as two to 100 sites. By adding specialized network control systems to the large central master earth station in a VSAT network its capacity can be customized, divided and made available to small network users. When many small networks are combined and share the master earth station, a value added network is created. With a VSAT VAN it is possible to broadcast data and/or video to all locations in a single transmission.

VSAT [illegible]

path loss is greater compared to *C* band propagation. Nevertheless the enhanced receiving gain of VSATs is more than sufficient to counteract the weather related propagation loss and yet provide a high quality data communications service. This has resulted in a proliferation of VSATs. However, in two satellite systems such as Indian National Satellite (INSAT) and

ARABSAT satellite there has been provided the unusual facility of special interest to developing countries. They have an arrangement by which transmissions sent in the *C* band will be amplified on board and braodcast on the *S*-band. The transmission in *S*-band has two advantages, namely (*a*) more powerful transmission in *S*-Band than *C* band and (*b*) cheaper in cost for antennas and receivers required for *S*-band reception. In addition, direct broadcast receivers have been produced in large numbers at low cost for use in receiving *S* band TV transmissions. While they are designed for direct reception of TV transmissions, they can be used for data broadcast reception as well. The above technique of transmitting to the satellite in *C* band and broadcast carried in *S* band is often referred to CXS scheme. Though this will require a special transponder on the satellite but the scheme can be implemented using a single channel per carrier (SCPC) modem.

The fundamental characteristics of such VSAT network require the use of low power transmitters (1-2 watts for ku band) with small 1.2-2.5 metre) antenna but relatively high EIRP from the satellite. This results in a situation in which satellite itself is used in a power limited mode rather than a bandwidth mode. The network is generally operated in a frequency division multiple access (FDMA) mode with several narrow bandwidth carriers because the maximum available bit rate from any VSAT is relatively small compared to the available bandwidth. However, because of bursty and diverse nature of VSAT data traffic multiple access schemes such as FDMA and TDMA do not in general utilize the available satellite channel efficiently. Dynamic accessing may be useful but it is seen that packet-oriented multiple access schemes are most suitable. These schemes may be classified into two broad categories, namely *contention or random access schemes* and *reservation schemes*. The main contention schemes suitable for use in VSAT schemes are based on the ALOHA concept of which there are three variations, namely pure ALOHA, slotted ALOHA and reservation ALOHA. These three protocols are suitable for balanced system in a broadcast channel.

VSAT systems are, however, unbalanced and consist of a large central or hub and a large number of VSATs. For such a situation RA/TDMA protocols are found to be much successful. Table 12.10 gives a summary of various multiaccess protocols applicable to VSAT data networks.

Table 12.10 Summary Comparison of Mutliple Access Protocols Applicable to VSAT Data Networks

Multiple Access protocol	*Capacity (max throughput)*	*Delay*	*Stability*	*Robustness*	*Vsat cost/ complex*	*Remarks*
TDMA	0.7-0.8	med-high	good	medium	medium	Delay increases sharply with the number of Stations
FDMA-SCPC	0.7-0.8	med	good	high	very low	Applicable only to high traffic Stations
	FIXED	ASSIGNMENT		TECHNIQUES		
	RANDOM	ASSIGNMENT		TECHNIQUES		
ALOHA	0.13-0.18	low	poor	high	very low	Applicable to variable length messages, tuning not required
Slotted ALOHA	0.25-0.368	low	moderate	high	low med	Simplest Slotted technique; Suitable for fixed length message traffic capacity competitive with slotted Aloha without tuning
SREJ-ALOHA (selective reject)	0.2-0.3	low	moderate	high	low	Well suited to variable length messages
Tree CRA	0.43-0.49	med	good	poor	med-high	Suitable for fixed length messages, interleaving delay & deadlock problems
ARRA	0.5-0.6	low	moderate	med	med- high	Side information used to improve slotted Aloha type channel performace

Multiple Access protocol	*Capacity (max throughput)*	*Delay*	*Stability*	*Robustness*	*Vsat cost/ complex*	*Remarks*
Random Access CDMA	0 1-0.4	V-low	moderate	high	med	Offers low delay with SSMA advantages, operated with or without tuning, complex FEC required for good through put
Time of arrival CRA, FLAP etc	0.4-0.7	low	moderate	high	med	Exploits arrival time information in collisions to improve performance of ALOHA channels
	Controlled Access Techniques					
DAMA/TDMA	0 6-0 8	med-high	good	poor	high	generlly attractive for long messages; high latency delay due to reservation

above and other advanced concepts. These and other useful trends and technologies would reduce equipment costs etc. of *VSATs*. The size of *VSAT* antennas is believed to be reduced in near future and there phased array antennas might be used instead of parabolic reflectors. Further as the technology develops in next 10 years it will be possible to locate VSATs in doors in many places. Also then more power with satellites would be available.

12.5. Mobile Satellite (MSAT) Communication System

In recent years the two areas of satellite communications which have been gaining major thrust from leading satellite industries and organisations are (*i*) very small aperture terminal (VSAT) fixed satellite communication systems and (*ii*) Ultra small aperture terminal mobile satellite (MSAT) communication systems. *VSATs have already been discussed in Section 12.4. The driving* forces behind these developments are technology advances, deregulation and market demand. MSAT terminals which can be called 'VSAT-on-wheels' have several features in common with VSATs. While the VSATs take communication services direct to fixed user premises, MSAT terminals take them to moving vehicles. They both fully exploit inherent satellite strengths, *viz*., universal coverage, uniform cost, network flexibility etc.

MSAT systems may be easily said to have a marriage between satellite and mobile phones. Examples are those of Canadian MSAT and the MSS of United States. These MSAT systems provide direct satellite service to mobile phones and thus are bound to provide greater improvement in rural communications. MSATs are superior to cellular radio services which can be found in western nations on cars, buses, trucks, trains and other specialized vehicles. This is because of the fact that [illegible]

[illegible] limited coverage areas have been responsible for the development of mobile satellite systems/services.

In such mobile satellite systems, the direct service by satellite to mobile phones requires one or more satellites in geosynchronous orbit, operating in the 800 MHz range with high effective radiated power. Narrow band power efficient modulation [illegible]

[illegible] attributes. Direct communication links can be established between a satellite and a variety of stations: mobile units, portable units, gateway earth stations, [illegible] rio, each base [illegible] ovides a con- [illegible]

and (*iv*) satellite and network control. The network is capable of serving many mobile stations, a somewhat smaller number of base stations and gateways and the operations center.

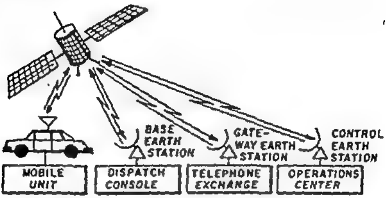


Fig. 12.12. Possible Network Structure of MSAT.

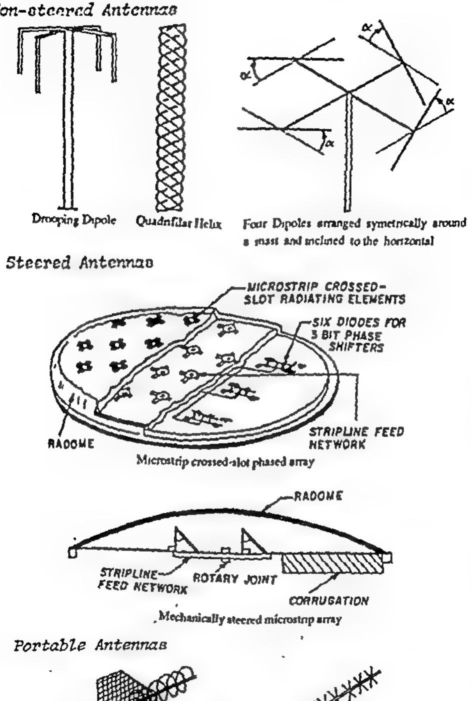
For MSATs it is essential that the satellite must provide sufficient radiated power in the direction of coverage area. Radiated power depends on the power available aboard the satellite and the gain of the satellite antenna. Very large and high gain antennas are capable of providing multitude of spot beams. Satellite with an uhf antenna of 3 to 10 metre size would be sufficient to provide several spot beams. NASA dreams to use in future large antennas capable of providing about 90 spot beams that would be able to cover the area of the size equal to that of USA.

Mobile stations use two classes of mobile antennas namely the steered and non-steered. The nonsteered (4 to 8db) is omnidirectional with regard to azimuth. Steered antennas (with more than 8db gain) is directional with regard to azimuth and tracks the satellite being use as the mobile units. In all cases circular polarization is being used. Various possible structures of such atennas are shown in fig. 12.13.

12.6. Search and Rescue Satellite (SARSAT) and Lower Earth Orbit (LEOs) Satellites

Such a satellite system is used for receiving passangers and crew members of sinking ships or crashed airplanes. The system is used also in USSR under the Russian terminology Cospas. Therefore the SARSAT is also oftenly termed as *Cosapas-sarsat. The satellites circle the globe at 1000 kilometer altitudes in scanning a wide swath of the earth for distress signals and relaying them to* specially built earth stations. It must be noted that this system is quite different to INMARSAT which is aimed mainly to commercial maritime industry.

... in the subarctic Atlantic, satellites direct distress signals and alert ... teams.


Non-steered Antennas
α
α
α
α
Drooping Dipole
Quadrifilar Helix
Four Dipoles arranged symetrically around a mast and inclined to the horizontal
Steered Antennas
MICROSTRIP CROSSED-SLOT RADIATING ELEMENTS
SIX DIODES FOR 3 BIT PHASE SHIFTERS
RADOME
STRIPLINE FEED NETWORK
Microstrip crossed-slot phased array
RADOME
STRIPLINE FEED NETWORK
ROTARY JOINT
CORRUGATION
Mechanically steered microstrip array
Portable Antennas
Helix with reflector
Crossed-dipole yagi

F[illegible] 12.13 [illegible]

A marine signal received by an INMARSAT satellite on the other hand would be relayed to one of Inmarsat's earth stations and from there transmitted directly to a rescue coordination center. It is believed that a simple distress beacon-self powered, automatic and rugged would cost about $ 50000 in mass production. At this price, many airplane, boat and ship owners would be able to install a beacon. For large ships the beacon would be integrated with the voice and telex satellite communication equipment; the beacon would account for only modest part of the $ 35000 price of the entire system.

As mentioned above the Sarsat system is a low polar orbit satellite which can be also termed as LEO satellite (low earth orbit). Such satellites instead of remaining over one spot over the earth encircle it, passing over the Poles. The earth's rotation brings the satellite within view of every point on the ground several times a day. Such LEO satellites are also being used for communication services (*store and forwared satellite communication*). Typical example of such a satellite is UOSAT-2 of the University of Surrey Spacecraft Engineering Research Unit, U.K. In such communication system digital messages are transmitted to the LEO satellite when it is over one ground terminal. They are stored in computer memory on the satellite and then transmitted back to the earth when the satellte passes within range of the destination terminal. Such satellites have the advantages of being accessible even to polar regions.

12.7. Satellite Communication with Respect to Fibre Optic Communication

Fibre optic communication and the satellite communication are being developed continuously on parallel courses for the last two decades. The capacity of these systems has greatly expanded over the last 20 years. Terrestrial wideband communication systems and communications satellite facilities are both on the order of 200 [illegible]

'increased risk' is an essential feature of the new telecommunication environment. It is therefore essential to study the coexistence of fibre optic cables and satellites and also the economic tradeoffs between the two technologies.

The first approach to study the two technologies would be to have a comparative study of their capabilities. Table 12.11 discusses the same. From above Table 12.11 it is evident that neither of technology can replace each other though it is true to some extent that for many applications where satellites once looked attractive, fibre has come in and dried that up. It is true that fibre optics will impinge on the dominance of satellites in certain long distance communication routes between two points. [illegible]

are also strong for sparesely populated regions where the relatively low volume

In Cospas-Sarsat system a small industry powered transmitter on a ship or aircraft is activated-manually or automatically in an accident. Once activated, the transmitter of beacon emits a low power omnidirectional signal that is picked up by a satellite. The satellite then relays the distress signals to an

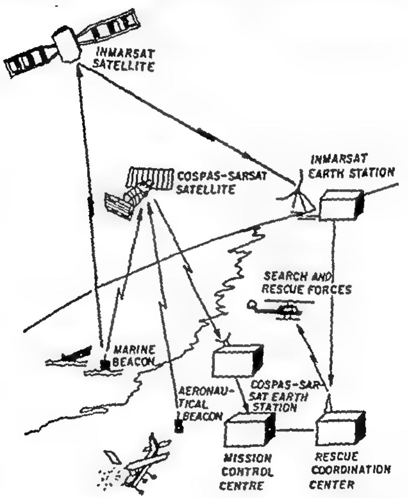


Fig. 12.14. Cospas-Sarsat Satellite with INMARSAT for Maritime Services.

signals picked up by the Cospas-Sarsat satellite would follow a similar route.

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Whereas there has been considerable advances in optical fibre communications such as those of dispersion shifted fibre which are capable of providing practical transmission rates exceeding 1Gb/s over distances as great as 150 km satellite communication advancements are not lagging behind. Satellite communications technology is unchallengable for point to multipoint communication. Satellites in 14/12 GHz band are already in use. Frequency reuse with on board processors have greatly increased satellite flexibility and capacity. Scanning spotbeams, channel switching particularly combined with companded single sideband modulation have increased satellite capacity to great extent. Teleports and Satellite Platforms in space are examples of latest advancements particularly for the years 1990s.

Inspite of these developments in both the technologies now the main turning point is on digital transmission of information. Though for some cases e.g. point to point, as mentioned above digital transmission of optical fibre links are quite useful but the establishment of a fibre optic link first requires finding a right-of-way for the line, a complicated and expensive task in densly populated regions or areas with rugged terrain. In such a situation satellite communication is useful. VSATs, microearth stations, MSATs etc. can not be overpowered by the fiber optic communication. Thus it can be easily concluded that neither of these two of these super technologies can compete each other but instead would be of high useful if both used as complimentary to each other. Such a joint venture of fibre optics and satellites are already performed in Teleports. Here high capacity fiber optic links are used to link satellite networks in teleports with customers or locations with high volumes of communication traffic. For such a case microwave transmission is not useful as it would cause interference particularly in cities already criss crossed with many microwave links.

It is belived that in future fibre optics submarine cable would be cost effective than the satellite communication. A typical consideration is that as given in Table 12.12. The above Table 12.12 indicates that with the improvement in technology fibre optic submarine cable is going to have not [illegible]

submarine cable increases with the distance. It is seen that the cost analysis has indicated that the submarine cables are cost competitive upto a certain distance, called 'cross-one' distance. For the most advanced cable system the cross over distance with a 'total fil' scenario is 3545 km, *e.g.* in PTAT-1. This has shown that on a long haul point to multipoint communications satellites have a definite edge over the submarine cable system. However, taking into account all the considerations it is seen that cost of a satellite circuit is almost double that of submarine cables and therefore most of the users are in favour [illegible]

greater capacity to fibre optics, similar lifetime and lower costs. Regarding

These LANDSAT-4 and LANDSAT-5 satellites are in circular sun synchronous near polar orbit at an altitude of approximately 705 km. They circle the earth every 103 minutes completing 14 orbits per day and view the entire earth in 16 days. The orbit is selected and trimmed so that each satellite ground trace repeates its earth coverage at the same time every day. There are many reception stations the world over which receive data from Landsat satellites. This is further processed and the data disseminated to the users. In India there is an earth station at Hyderabad that was set up in 1979 to receive data from Landsat 2 and 3. The data acquired from the Landsat system permits quantitative measurements of the earth surface characteristics to be made on spectral spatial and temporal basis. Besides the Landsat series of satellites presently in operation are the Indian IRS-1A and the French SPOT-1 satellites. European Remote Sensing Satellite ERS-1 is scheduled to be launched in 1989 whereas the Canadian Radarsat satellite is to be launched in 1991. These two satellites will be carrying microwave sensors. It would be of importance to mention here that in 1990s there is going to be a vast earth observing system worldwide *e.g.* the NASA's upper atmosphere research satellite (UARS), TOPEX, the Geopotential Research Mission (GRM) and the International Solar Terrestrial Project (ISTP). Satellite like NOAA, GOES, LANDSAT-5, 6, N-ROSS, ERS-1, MOS and other ocean observing satellite shall be launched Advanced Data Collection and Location System (ADCLS) shall be employed. Some other latest measuring equipment shall also be employed. These are moderate resolution imaging spectrometer (MODIS) high resolution imaging spectrometer (HIRIS), high resolution multi frequency microwave radiometer (HMMR), Liquid atmospheric sounder and altimeter (LASA), synthetic Aperture Radar, Radioaltimeter, Scatterometer, Doppler, Radar, upper atmospheric wind inferometers, tropospheric composition monitors, upper atmosphere composition monitors, energy and particle monitors.

12.9. Defence Satellites

Military or Defence satellites have now a days become quite important for national security. They have proved their significant strategic importance to defence forces everywhere. These are capable of providing message, data and live telecasts across international boundaries (more loosely from any part of the world). Infact the present day balance of power depends on them and so techniques are also there to save them in case they are being attached by a killer satellite from enemy or so. The two superpowers namely the USA and USSR have a keen competition on it and it can't be easily said as to who exists where. The SDI (strategic Defence initiative) Star wars programme of USA has opened a new vista in military satellite activities. Actually modern electronic warfare completely depends on satellite.

Military satellites may be both non weapon or weapon satellites but it is the non-weapon ones that have been mostly used for a variety of purposes. SDI's have initiated the program of weapon satellites. Table 12.15 lists the non-weapon satellites owned by USA and USSR upto 1987 level. From Table 12.15 it can be seen that such non - weapon military satellites are of roughly

Table 12.15. Non Weapon Military Satellites of USA and USSR

Type of satellite	*Country*	*Pre 1980*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*Total*
Photographic Reconnaissance	USA	231	2	2	2	2	3	1	244
	USSR	466	35	37	35	37	36	34	680
Electronic Reconnaissance	USA	78	1	0	1	1	1	1	83
	USSR	115	6	4	6	6	5	9	151
Ocean Surveillance	USA	11	4	0	9	0	4	-	28
	USSR	20	4	8	9	2	4	5	52
Early Warning	USA	20	0	2	1	0	-	-	23
	USSR	15	5	5	5	3	7	7	47
Navigation	USA	36	2	1	0	1	3	3	46
	USSR	47	6	5	11	13	8	4	94
Communications	USA	113	3	2	2	0	6	6	132
	USSR	291	36	39	26	26	23	15	456
Meteorological	USA	69	2	2	0	1	1	-	75
	USSR	57	2	2	2	1	1	3	68
Geodetic	USA	19	0	0	0	0	0	1	20
	USSR	16	0	0	0	1	0	-	17

six primary categories, namely the reconnaisance satellites, early warning satellites, navigational satellites, communication satellites, meteorological satellites and geodetic satellites. It may be realized that each of the above six kind of military satellites plays an important role in military operation.

Reconnaissance satellites were the first which were deployed for military purposes. These are used to monitor objects and their movements on the ground. There are 3 kinds of such reconnaissance satellite, namely, the photo-reconnaissance, electronic reconnaissance and ocean reconnaissance satellites. Photo reconnaissance satellites are mostly used for monitoring conflict areas. Initially these were meant for area surveillance and were aimed at scanning large areas of strategic importance. Such satellites had short life of span of three to 5 weeks and were mission oriented. Such satellites could take photographs only when they were in orbit and were not in a position to transmit photographs back to earth. The major break-through in photo-reconnaissance satellite came in 1971 with the launch of Big Bird satellite of USA under the name of Low Altitude Survelliance Platform which was equipped with high resolution cameras and six recoverable film capsules. The satellite was capable of sending pictures even when it was in orbit. The statellite had lifetime of only 52 days.

Table 12.16. Comparative Developments in USA and USSR Military Satellites

Types of Satellites	*Typical Developments*		*Date of first Development*	
	USA	USSR	USA	USSR
Photographic Reconnaissance	2-3 low orbit	1-5 low orbit	1959	1962
Electronic Intelligence CELINT	1-2 Geosynch	6 Low orbit	1962	1967
Ocean surveillance	6 low orbit	2-4 low orbit	1976	1967
Early Warning	3 Geosynch	9 Molniya	1960	1971
Communications	11 Geosynch 2 Molniya	27 low orbit 12 Molniya 12 Geosynch	1959	1964
Navigation	5 low orbit 6 Semisynch	10 low orbit 9-12 Semi-synch	1959	1967
Meteorology	*2 low orbit*	*3 low orbit*	*1963*	*1963*

Subsequent to the launch of Big Bird several photo-reconnaissance sat-

Electronic reconnaissance satellites also called as Electronic Intelligence

ment may be successfully used. *Ocean reconnaissance satellites* are used to locate targets of military importance at sea, say about naval force such as ships, submarines etc. Operation of such satellites is based on the use of sensors that measure the difference between the temperatures of sea cool water and water

launched ballistic missile (SLBM).

Table 12.17. Types of Sensor on Board Satellite

Sensor	*Functions*	*Types of Satellite*
Photographic	Detection of ABM systems, ICBM and cruise missile deployment, military facilities and troop movements	US photographic reconnaissance satellites such as the KH services and many of the Soviet Cosmos satellites
Infrared	Detection of missiles, aircraft and cruise missiles (potentials)	US and Soviet early warning satellites
Nuclear Radiation Detectors	Detection of nuclear explosions in the upper atmosphere and in outer space	US Vela satellites and IONDS-Integrating operational Nuclear Detection System-carried on Board the GPS navigation satellites
Ultraviolet	Detection of fluorescence from gases surrounding booster or nose cones during ballistic flight.	US and Soviet early warning satellites
Elecronic signal detectors	Radio and microwave telephonic transmission interception, radar signal detection, missile telemetry interception	Soviet Cosmos and US electronic reconnaissance satellites. US Rhyolite and Chalet satellites in geostationary orbit
Radar	Detection of Naval surface ships, many other ground based military objects	US Seasat-1 and Cosmos Ocean surveillance satellites
Thermal Infrared scanners or radiometers	Night time reconnaissance detection of targets such as burried structures of underground construction.	US Seasat-1

Early warning satellites are used to get information about and to detect, intercept and destroy an incoming enemy nuclear missile before it impacts on its targets. It is done by the use of infrared sensors of the satellite that are sensitive to infrared radiation emitted by the hot plume of rockets when the satellite is launched. To have better performance TV cameras are also placed on board such satellites to send pictures to ground stations. Such satellites are capable of sending information about the launch of missile to the ground station within 3 minutes and the trajectory and other characteristics of missiles can be established within 5 minutes.

Communication satellites of military are responsible for communication between various ground stations of military command located at different locations. C^3I (command, control, communications and intelligence) is transmitted *via* communication relays. Worldwide military command and

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Meteorology	2 low orbit	3 low orbit	1963	1963

Subsequent to the launch of Big Bird several photo-reconnaissance satellite with greater life time say about 300 days have been launched by both USA and USSR. USA launches photo-reconnaissance satellite about 3 a year whereas USSR launches several but with shorter life spans. A comparative study of photo-reconnaissance and other such satellites of USA and USSR are given in Tables 12.16 and 12.17. The Russian such satellites are widely known as COSMOS series. It may be noted that China had also launched a photo-reconnaissance satellite on 26th July, 1975.

[illegible]

submarines etc. Operation of such satellites is based on the use of sensors that measure the difference between the temperatures of sea cool water and water released by submarine. Ocean reconnaissance satellites have oftenly been used in previsus wars such as those of Jordan Crisis of 1970, Indo-Pak war of 1971, Naval exercises of superpowers in 1973; 1975. Lebanon war with Israel in 1983, crisis of Gulf in 1987. Technological developments in such satellites are taking place every year. Typical examples are those of Soviet interferometric sensor satellites and US Geostat satellite. Geostat satellites are used to measure earth's gravitational field so as to improve accuracy of submarine launched ballistic missile (SLBM).

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control system (WWMCCS) is completely based on such military communications satellite. USA uses military communications satellites under different headlines such as Defence Satellite Communications Systems (DSCS)II, Air Force Satellite Communication System (AFSATCOM), the fleet satellite communications system (FLTSATCOM), satellite data system (SDS), military strategic tactial and relay satellite communications (MILSTAR), Airforce's Strategic Satellite System (SSS). Soviet Union also has several military communication satellites mostly under Molniya series.

Military Navigational satellites are used to determine the precise locations and velocity of mobile weapon systems such as aircrafts, missile and submarines. These are mostly jam resistant. Typical examples are NAVSTAR GPS of USA and GLONASS of USSR. Meteorological satellites provide predictions about weather and atmospheric conditions such as information about temperature patterns at different altitudes, wind direction, water wapour, radiations, atmospheric density, electron and ion density etc. The data is stored at a central place. In USA weather data is processed and stored at USAF Global Weather Center at Offult Air Force Base in Nebraska and the Fleet Numerical Weather Center in Monterey, California. Soviet Union also possesses an [illegible]

beam data directly to mobile receiving sets installed on weapon carrying platforms. Geodetic satellites give information about earth's gravitational field which is of high importance to nuclear and potentially nuclear weapon states. It helps for error-free computations of trajectories and computations in the inertial guidance systems of missile and aircraft. Also, it is being used for photomapping the earth's surface for precise ballistic missile launch and *impact-point location functions.*

Superpowers are trying to devise methods to destroy, kill and steal the enemy's satellites. They are developing ground based laser systems to do so. [illegible]

12.10. Teleports

Teleports are the facilities or platforms which have at least 13 or more [illegible]

operational, planned or under development in USA (1987 report). 4 are planned [illegible]

for Teleport to sustain that it should be able to serve in an area at least 150,000 homes or more particularly in densest regions. Trend is therefore toward the development of miniteleports.

On analysing the reasons for the development and investment in teleport service, four basic reasons have been seen namely, enterpreneurial, nature (23 in number), bypass purposes (19 in number), economic development (8 in number) and real state development (2 in number). Bypass means here to avoid existing communication networks of telephone companies such as those in USA, PTT, AT&T and Bell Canada etc. The users of North American Teleports are of 6 categories (year 1986 based report). 60 percent of customers of Teleports were either broadcast or CATV users, 10 percent were represented by common carriers, 10 percent by business and 10 percent by government users and finally 10 percent by miscellaneous occasional - time users. However, it is believed that by 1992, CATV and broadcast users would represent [illegible]

expected to tripple respectively by 30 percent each. Government and miscellaneous teleport usage are expected to remain constant.

The status of Teleports in USA is given in Table 12.18. It is evident from this table that Teleports in North America are distributed in the densest metropolitan regions, in the eastern half of the continent where one would naturally propose such facilities. Such a distribution gives teleport access to highly dense business locations and also makes them subject to competition from the new and abundant fibre optic network. Operators of these new network are installing very high capacity fibre transmission systems along these 'heavy' eastern continental routes.

Most of teleport traffic is analog at the moment. Thus in 1986, 83 percent of teleport revenues were from video traffic, 10 percent from voice traffic and seven percent from data. By 1992 these proportions shall start equalizing because competitive and industry factors should affect Teleport operations such that 60 percent of teleport revenues will be primarily video based, 20 percent voice based and 20 percent data based. By 1996, these proportions will have continued to reverse and 20 percent of teleport revenues will be video based, 40 percent voice based and 40 percent data based. There is a feeling among public as well as in Government that Teleports are necessary for economic development and therefore people would be encouraged to invest in Teleport. It is also hoped that Teleports will provide interface to business and other automation and technology users who will be making large capital investments in the ISDN environment. Teleports are also hoped to provide multinational services in future.

Table 12.18. Teleports in Americas

LOCATION	*TELEPORT*	*OPERATIONAL*	*DEVELOPING*	*PLANNED*
ALABAMA				
Birmingham	Alabama Teleport			×
CALIFORNIA				
San Francisco Bay	Bay Area Teleport	×	(×)	
Los Angeles	Los Angeles International Teleport	×	(×)	
Rancho Mirage	Eisenhower Med Center Teleport		×	
COLORADO				
Denver	Aerocom Teleport		×	
Denver	Teleport/Denver		×	
Colarado Springs	World Star West			×
DISTRICT OF COLUMBIA				
Washington	Washington International Teleport	×		
Washington	The National Teleport		×	
Washington	DC Teleport	×		
FLORIDA				
Hollywood	Miami Teleport			×
Miami/Ft. Lauderdale	South Star Communications	×		
Ocala	Central Florida Teleport	×		
Orlando	Orlando Telecomm Port		×	
GEORGIA				
Atlanta	Turner Teleport	×		
Atlanta	Up South	×		
Atlanta	Crawford Satellite Services		×	
Douglasville	Atlanta International Teleport	×		
HAWAII				
Honolulu	State of Hawaii Teleport			×
Honolulu	Hawaii Loa Teleport			×
ILLNOIS				
Chicago	Chicago ETC	×		
Chicago	Teleport Chicago	×		
IOWA				
Des Moines	The Iowa Teleport	×	(×)	

LOCATION	*TELEPORT*	*OPERATIONAL*	*DEVELOPING*	*PLANNED*
MASSACHUSETTS				
Boston (Belmont)	Boston Teleport			×
Boston	Boston Teleport (Taft)	×		
MICHIGAN				
Detroit	Northern Teleport	×		
MINNESOTA				
Minneapolis	Twin Cities Teleport	×		
MUSSOURI				
Kansas City	Kansas City Teleport	×		
St. Louis	St. Louis Teleport	×		
NEW JERSEY				
Carteret	National Gateway Telcom.	×		
Fairfield	Crescomm Teleport	×		
NEW YORK				
New York	The Teleport	×		
New York	Manhattan Teleport	×	(×)	
Long Island	Long Island Teleport	×		
NORTH CAROLINA				
Releigh	Capitol Earthbase	×		
OHIO				
Central Ohio	Great Lakes Teleport			×
Columbus	COM III	×		
Columbus	Ohio Teleport Corporation			×
OKLAHOMA				
Oklhoma City	The Oklahoma Teleport	×	(×)	
PENNSYLVANIA				
Harrisburg	Harrisburg Teleport	×	(×)	
Pittsburgh	Armstrong International Teleport	×		
Roaring Creek	Roaring Creek International Teleport	×		
Scranton	Pennsylvania Teleport			×
TEXAS				
Austin	Austin Teleport			×
Dallas	Dallas/Ft. Worth Teleport	×		
Dallas	Metroplex Teleport	×		
Houston	Gulf Teleport			×
Houston	Houston International Teleport	×		
Houston	Houston Gateway Teleport			×
San Antonio	Texas Teleport			×

LOCATION	*TELEPORT*	*OPERATIONAL*	*DEVELOPING*	*PLANNED*
WASHINGTON				
Seattle	Vashon Island (Seattle Teleport)	×		
CANADA				
Calgary	Calgary Teleport			×
Montreal	Teleport de Montreal		×	
Toronto	Toronto Teleport			×
Vancouver	Vancouver Harbor			×
JAMAICA				
Montego Bay	The Jamaica Teleport			×

(X) = Operational with significant construction remaining

12.11. Geostationary Space Platforms

The word 'platform' for satellite communication means a very large spacecraft to be put in geostationary orbit. This is supposed to be an efficient means of increasing the capacity at a point in the geostationary orbital arc. Infact Geostationary Platform is considered to be a solution to the crowding of the orbital arc since it could provide the functions of many individual satellites of conventional design. It is also considered to carry very large antennas required for mobile communications or broadcast services, earth observation and other science payloads. All these ideas led to the study of feasibility of space-platforms and it is believed that by mid 1990's a trial space platform at low earth orbit will be launched by USA and thereafter Geostationary Space platform would be launched. Table 12.19 shows the milestones of the Geostationary Platforms progress in USA.

Table 12.19. Milestones of Geostationary Platform Programs.

Year	*Remarks*
1974-1978	* Genesis of concept, based on OAF (orbiting Antenna Farm) * Shuttle assembly concepts introduced. * Orbital arc efficiency drivers * Industry studies by NASA * Political problems in multiple ownership investigated.
1979-1981	* NASA/Comsmat/General Dynamics Study for single shuttle payload platform.
1981-1984	* NASA workshop at Huntsville in 1981 * NASA concept updates presented at various AIAA communications satellite systems Conferences * Mitsubushi and NASDA concepts developed ESA, Aeritalia, and MBB concepts/proposals.

Year	Remarks
1984	* NASA started Space Station Development.
	* NASA introduced staging base concept for space station
	* Growing arc saturation at GEO at both C-band and Ku-band.
	* Payload definition contracts to Ford and RCA for geostationary platforms by NASA.
	* Bus definition contracts to Ford and Lockheed for geostationary platforms
1985	* Completion of NASA payload/bus contracts
	* Science utilization proposals for geostationary platforms were introduced to the SESAC Task Force/Committee at Standford Summer Study
	* Proposals of geostationary platform for sound broadcasting.
	* British Aerospace proposal for 'big communications'
Future	* Geostationary platforms as members of post-IOC era

Space platforms are considered to have several significant advantages such as (*i*) improved conservation of the geostationary arc by utilization of the radio frequency spectrum at a given point in the geostationary arc through the use of multiple payloads, giant antennas and on board signals routing and processing, (*ii*) increased data capacity per unit of arc, (*iii*) economics of scale due to shared bus, power systems, attitude large amounts of dc power from a common source and (*iv*) synergism of collocating disperate payloads involving both communication and science. It may be noted that geostationary platforms are also not free from disadvantages. The disadvantages may be (*i*) high launch costs both earth to LEO and LEO to GEO, including the need to develop LEO to GEO transfer systems, (*ii*) service complexity associated with servicing during operations and (*iii*) difficulties in integrating disparate payloads. Inspite of these disadvantages the Space platform is on offing and the geostationary platform may join the space station family around the turn of the century to : (*a*) serve many scientific functions which can only be accomplished from a geostationary position, (*b*) reliance the growing congestion of commercial communication satellites populating the geostationary arc, (*c*) make use of large antennas (20-100 m diameters) working with supercomputers to turn points in the geostationary arc into space communication centres and into space science and relay centres and (*d*) provide dc power to enable payloads which can not be sufficiently powered as independent research.

Space stations alongwith the objectives mentioned above, have aims developing the capacity to assemble, service and repair satellites and other large structures in space. Space station is a complex family which at the initial operating capability (IOC) includes the LEO manned space station module, coorbiting platforms, tethered platforms or spacecrafts, free flyers, unmanned [illegible]

MEGALOS program of ESA. These are also to be launched by the end of present century. Once the space station and geostationary platform concept are finalized, some advanced communications payload concepts would be developed that would have an enormous antenna or antenna complex. Such a platform would also support large dc power capability and a major communication node which would include the growing use of computer in space.

12.12. Communication Satellites of Nations Other Than USA, USSR and International Organisations

Considering the fact that improved communication is necessary for the national economic development, several countries round the globe have been

equipped with broadcast mission devices. The above list shows that though the USA & USSR own satellites in maximum number but others are not lagging behind. In Europe, there is an organisation called EUTELSAT modelled after INTELSAT. There are 20 number states (signatories) of EUTELSAT. At present EUTELSAT owns its communication satellites EUTELSAT-1 (ECS) *that is operational since 1983/1984. Its second version EUTELSAT-II is* scheduled to be launched in 1990.

Actually in Europe, work on satellite was started by European Space Agency (ESA) which has developed its experimental OTS satellite from which

Luxembourg the Societe Europeene de Satellite (SES) since 1988 has the satellite called GDL/ASTRA that is totally dedicated to Europe wide distribution of TV programmes. In Italy work is going on ITLASAT that is to be launched in 1990.

(France) are also being developed for DBS services. In UK the DBS system UNISAT is to be launched soon The USSR and its allies (Bulgaria, Cuba, Czechoslovakia, East Germany, Hungary, Mongolia, Poland and Rumania) have a consortium called INTERSPUTNIK for developing communication facilities to its signatories members. Now the signatories to INTERSPUTNIK include Afghanisatan, Laos, South Yemen, Syria, Vietnam, Algeria, Iraq and North Korea. INTERSPUTNIK operates both MOLNYA satellites orbiting

Table 12.20. Status of World's Comunication Satellites.

Continent	*Country/Organ.*	*In Operation*	*Under Planning*
North & South America	USA	More than ten systems are now in practical operation WESTAR, SATCOM, COMSTAR, SBS, GALAXY, TELESTAR-3 SPACENET, GSTAR, ASC. AURORA.	Nearly 10 systems slated (incl. ABCI, RSI, USAT, FORD-SAT)
	Canada	ANIK-C&D	ANIK-E (Scheduled for 1990)
	Mexico	MORELOS	
	Brazil	BRASILSAT	
	Columbia		SATCOL
Europe	EUTELSAT	ECS (EUTELSAT-1)	EUTELSAT-II scheduled in 1990.
	West Germany		DFS-Kopernikus (schedule in 1989)
	France	TELECOM-1	TELECOM-2 (scheduled in 1991)
	Sweden & other Nordic countries		TELEX (quasi practical communication / broadcast satellite scheduled in 1989)
	Luxembourg	ASTRA	
	USSR	MOLNIYA, STATSIONAR, (RADUGA, GORIZONT)	
Asia, Oceania, Africa	Japan	CS-3	JC-SAT (scheduled in 1989) SCS (scheduled in 1989)
	Indonesia & ASEAN COUNTRIES	PALAPA-B	PALAPA-C (around in the middle of 1990s)
	India	INSAT-1 (communication/Broadcast/weather)	INSAT-II (scheduled in 1990/1991)
	Australia	AUSSAT-A (Communication broadcast)	AUSSAT-B (communication/broadcast/mobile, scheduled in 1992)
	Arab Countries	ARABSAT (Communication broadcast)	
	Israel		AMOS (Communication/broadcast, scheduled in 1993

Table 12.21. Major Specifications of Satellites Equipped with broadcast Mission Devices

Name of satellite (country	*Mission*	*Weight*[*2] *of satellite (kg)*	*Transmission frequency (GHz)*	*Transmponder output (W)*	*Channels available for broadcast*	*Maximum EIRP (dBW)*	*Launched (First satellite)*	*Remark*
BS-2 (Japan)	Broadcast	355	12	100	2	58.4	1984 Jan.	Experimental broadcast (one channel) started on May 12, 1984
BS-3 (Japan) STC DBS (U S)	Broadcast Broadcast	550 650	12 12	120 200	3 3	58	1990 (slated)	STC withdrew from DBS business at the end of 1985
USSB (U.S) ANIK-C (Canda)	Broadcast Communication	1,300 567	12 12	240 15	8 (16)[*2]	54 51.5	1982. Nov.	Under pllanning Directly received with an antenna of 1.2–1.8m diameter
OLYMPUS-1 (ESA)	Multi-purpose	1,400	12	230	2	62.7	1989. (Slated)	Broadcast service using Italian and European beams
TV-SAT (West Germany)	Broadcast	1,180	12	260	4 (5 actually available)	65.7	1987. Nov	Inoperable due to a partial disorder (the solar cell panel on the north side not opened) No. 2 satellite to be launched in 1989
TDF-1 (France)	Broadcast	1180	12	260 230	≒ 4 (5 actually available)	64	1988 Oct.	Using a bus same as TV-SAT. Blast off of No. 2 scheduled on yeat later of No. 1
TELE-X (North Europe)	Broadcast Communication	1,200	12	230	3	65	1989 (slated)	The same bus as TV-SAT/TDF-1
UNISAT (U K)	Broadcast Communication	850	12	230	2	63.7		Project suspended in 1985

Name of satellite (country	*Mission*	*Weight*[*1] *of satellite (kg)*	*Transmission frequency (GHz)*	*Transmponder output (W)*	*Channels available for broadcast*	*Maximum EIRP (dBW)*	*Launched (First satellite)*	*Remark*
BSB (U K) ASTRA (Luxembourg)	Broadcast Communication	650 1,020	12 12	110 45	3 (16)[*2]	61 52	1989 (Slated) 1988. Dec.	HS-376 type bus Directly received with an antenna of 0.6–1m diameter
INSAT-1 (India)	Multi-purpose	620	2.6	50	2	42 (beam end)	a·1982. Apr. b·1983. Aug.	a's operation stopped in September 1982 Community recetion
ARABSAT (Arb countries) AUSSAT (Austrira)	Broadcast Communication Broadcast Communication	716 655	2 6 12.5	50 30	1. 4	41 (beam and) 51	1985. Feb. 1985. Aug.	Community reception HS-376 bus, Community reception
EKRAN (U S.SR.)	Broadcast	2,000	0 7	200	1	56 5	1976. Oct.	Community reception

[*1] Initial weight when the satellite was launched into the geostationary orbit
[*2] Number of channels available for communication

(stationary) satellites (RA-
rk is intended for telephony,
or direct
y operates
to have two more satellites

satellite was launched in 1985 by the Arab Satellite
countries. The system
w and medium
V distribution,
onesia and the
Australia has its communication
AUSSAT-B
in operation.
damaged
during mating with the launching rocket.
would be
also going to have its own satellite AMOS
s details are not well
ed its 11th 'retrieval'
ched successfully 20
hich returned to earth
k services for French and West
llite was launched on 5th August,
ys later along with two tor nes of
from West Germany.
to have ANIK-E
in 1990.
umbia also have
their own satellites such as Brazilsat, Morelos and
spectively.

12.13. Satellite Communication Towards Year 2000 and 21st Century

The main goal towards development of any satellite system is to provide a better, efficient and cheaper communication services to the customers. This
developments in technologies. Therefore, the future communication
has to take into account following 7
(ii)

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Increased High tech capabilities in communication technology have resulted in a host of service offerings through satellite communications. These include private data network using earth stations located at the customer's premises, direct satellite for home pay TV service, facsimile networks, international electronic mail, video conferencing, cable TV distribution, data collection and environmental monitoring network etc. Fibre optic cables have great impact on such services. Teleports etc. are just a few examples where satellites and fibre optic cables are complement to each other. Data communication networks and all other modern video communications are dependent on fibre optic cables. The capacity of fibre optic cable is increased to 2 Gbit/s.

Present day satellite communication is giving boost to *Ku* band satellites in Geostationary orbit for coming years. It is because of the fact that it would possible to locate these antennas in the midst of urban environment without regard to frequency interference since these frequency bands are little utilized for terrestrial communications links. At the moment there is problem of such *Ku* band satellites as they are expensive. Also the technology both in terms of travelling wave tubes (TWT's) and solid state amplifiers is less developed. To deal with the increased number of satellites in geostationary orbit, satellite clusters operating as many as 10-12 satellites in a single nodule point in the geostationary orbit may be designed. Another way is to deploy a geostationary orbital antenna farm that is a large platform capable of combining the effective performance of 50 or even 100 conventional communication satellites. Space station and Geostationary Platform would be another possibility to increase the number of possible satellites and to maintain their service activities.

Integrated Services Digital Network (ISDN) and the transition from analog to digital communication services are expected to take place in the 1990's. The ISDN environment would involve interconnection of domestic satellite systems with international satellite systems. Further the attempt is to reduce the 250ms delay of satellite transmission to 120ms and then ISDN and digital communications will clearly play a critical role in the future development of satellite communication. INTELSAT is also going to have in future the digital circuit multiplication and digital communications. The earth station antennas shall be going to be very small particularly for mobile satellite communications generally consistent with the shape, size and cost of a briefcase. These will be used by INTELSAT and other aeronautical and maritime services for disaster relief and other services.

Though international organisational satellite systems are increasing their activities but the developing countries like those of India, Brazil etc. are going to have their own communication satellite systems. Therefore now the International Satellite Systems will have to deal with mostly services other than domestic communication. Some of the developing countries are looking for the transfer of technology and indigenous development. Therefore much will [illegible]

[illegible]

would be having on board processing systems which have advantages of error

rate reduction, efficiency improvement, capacity enhancement, polling implementation, interference cancellation, data reduction, transponder linearization, sorting, routing and message distribution, flexibility through network interconnection, time reduction for error detection and retransmission and transmission channel equalization. It may, however, be noted that with above advantages there might be disadvantages too such as extra weight, power dissipation, decreasing reliability due to increase in complexity and cost. Therefore the INTELSAT or other organisation using on board processing will have to evaluate these tradeoffs judiciously before introduction to its future systems.

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THIRTEEN

Indian Activities in Satellite Communication

13.1. Introduction

India like any other developing country had long back realized the fact that better communication in the country is must for the national economic development. Space science, space technology and space communication have already established their significance for communication among masses particularly in rural areas and their link with other continents of the world. With these ideas India's commitment to space is part of her larger commitment to communicate to over three quarter of a billion of her population. Both research in space and in atomic energy started almost immediately after independence, and the space commitment increased with the growing responsibility of educating the illiterate masses whose number in numerical terms is almost five times to day than at the time of independence Dr. Vikram Sarabhai, the founder of Indian Space Programme in the 1960's had already envisioned the importance of space to the real problems of man and society of Indian subcontinent. It was made clear then to the developed world that India's space programme was not to compete with the developed countries' space programmes such as the exploration of the planets or manned space flights but its purpose was solely for the development of Indian nation in economic and social terms.

Indian activities in space technology started in the early 1960's with the firing of sounding rockets from Thumb a located on the magnetic equator to study the earth's atmosphere. *Ionospheric X-ray astronomical experiments* [illegible]

sounding rockets and payloads. At the same time an Experimental Earth

Station (ESCES) was established in 1967 at Ahmedabad with the help from UN and ITU. It was used for training engineers from India and other developing countries in handling advanced equipment. Since the establishment of ESCES, the development of satellite communications in India has been in constant advance. Technology development, studies, experiments and lauchers etc. have been going on leading to the establishement of operational facilities, use of INTELSAT and INMARSAT systems and establishment of a unique multi-agency multipurpose domestic satellite system, the Indian National Satellite System (INSAT). Remote sensing is also being fully utilized for a variety of services through Remote Sensing Satellite in India. Table 13.1. gives in brief about the Indian activities in Satellite communication area.

13.2. Operational Centres

In 1972 space commission was established by Indian Government which was later converted to Indian Space Research Organisation (ISRO) under the Government Department of Space (DOS). Headquarters of DOS and ISRO are located at Bangalore. The responsibilities of ISRO include the formulation of policy for DOS for approval and implementation by the Government. The DOS in turn is responsible for the execution of activities in space applications, technology and sciences.

ISRO has following operational centers, namely (1) Vikram Sarabhai Space Center (VSSC) located at Trivandrum. It is the ISRO's main development Center for the Rohini Sounding Rockets, SLV-3 and ASLV launcher series. It has also been responsible for the operation and maintenance of the

Table 13.1. Brief Summury of Indian Satellites

Satellite	*Launch date*	*Rocket/Agency*	*Site*	*Orbit*	*Purpose*
Aryabhatta	19 April.75	C-1 Inter Kosmos	Kapustin YAR (USSR)	619.56 × 562.31 Km incl 50.7°	Technology proving satellite
Bhaskara	7 June'79	C-1 Inter Kosmos	Kapustin YAR (USSR)	500 km near circular incl. 50.7°	Satellite for Earth Observation TV, radiometers
ROHINI RS-0	10 Aug'79	SLV-3 ISRO	Sri Hari Kota (India)	Failed to orbit	Technology proving satellite
ROHINI RS-1	18 July'80	SLV-3 ISRO	Sri Hari Kota (India)	900 × 300 km incl 44.74°	Technology proving satellite
ROHINI RS-D1	31 May'81	SLV-3 ISRO	Sri Hari Kota (India)	364 × 181 km incl 44°	Technology proving satellite, put into wrong orbit
APPLE	19 June' 81	Ariane, ESA	Kourou, Guiana	Geostationary 102°E	Communications satellite, test
Bhaskara-2	20 Nov' 81	C-1 Inter Kosmos	Kapustin Yar (USSR)	557 × 514 km Incl 50.7°	Satellite for earth observations, TV, radio materos
INSAT 1A	10 April' 81	Delta NASA	KSC/ETR, USA	Geostationary 74°E	Communications, Direct TV, meteorology functions

Satellite	*Launch date*	*Rocket/Agency*	*Site*	*Orbit*	*Purpose*
INSAT 1B	Aug'83	US Space shuttle		74°E	Functions same as that of INSAT 1A
Launch Vehicle	March'87	ASLV	Sri Hari Kota (India)	failed	Testing
Launch Vehicle	July, 13'88	ASLV-D2	Sri Hari Kota (India)	Failed	
INSAT-1 C	22 July'88	Ariane ESA	Kourou, French Guiana	93.5°E	To work with INSAT-1B
INSAT-1 D	June'90	Commercial Delta of MDC USA		83°E	To work with INSAT 1B and C, various communication services
IRS-1A	17 March'88	Vostok Soviet launch vehicle	-	904km polar sun synchronous orbit	Remote sensing
INSAT-1 1A, B		to be launched in 1991-1992	Guiana	Geostationary	Various commercial services

TERLS (*ii*) ISRO Satellite Centre (ISAC). It is located in Bangalore and carries out research and development in satellite technology. The Aryabhata, Bhaskara 1 and 2, Apple satellite, IRS-1A were designed and fabricated at ISAC, (*iii*) SHAR centre : It is located at Sri Hari Kota and has facilities for launching large sounding rockets and satellite vehicles. The main ground station for controlling satellites is here. SHAR also has facilities for the static testing of launch vehicle stages and for large scale production of rocket propellants, (*iv*) Space Applications Centre (SAC) located at Ahmedabad. It is the main centre for the development of practical space applications. The main activities include developing technologies for telecommunications and TV reception directly from satellites, surveying the natural resources of the country and space meteorology and geodesy, (*v*) Master control facility (MCF) located at Hassan (Karnataka State). The on orbit as well as the launch phase operations of the INSAT satellites are monitored and controlled from MCF.

In addition the DOS runs a Physical Research Laboratory at Ahmedabad and a National Remote Sensing Agency (NRSA) facility at Secundrabad *Andhra Pradesh that uses remote sensing data from the US Landsat satellites via* the ground station from Hyderabad. NRSA also disseminates data from IRS 1A. Recently National Natural Resources Management System (NNRMS) [illegible] at Bangalore has also been started under DOS. [illegible] noted that [illegible]

13.3. Satellite Instructional Television Experimental (SITE) Program

SITE programme was conducted during Aug. 1975-Aug. 1976 using the ATS-6 satellite of NASA. This programme was very valuable in building indigenous expertise (hardware, TV software and research and evaluation and managerial) for the future satellite communications and broadcasting programme of India. The main objective of SITE was to provide a systems test of the concept of satellite television and to gain experience in the development testing and management of a satellite based instructional TV system, particularly in the rural areas to determine optimal systems parameters. In fact SITE helped to design and test uplink stations, testing of TV sets, receive only sets (TVROs) and the low power limited area rebroadcast TV transmitters. Thus SITE was more than a technical demonstration cum experiment. It was a total satellite community reception TV system test in India and thus had equally important social, TV software and organisational aspects which were carefully studied and documented. It would be of importance to mention here that under SITE experiment that lasted over one year, 2400 villages in six states were able to receive specially made TV programmes related to agriculture and health care directly from ATS-6. Reception was accomplished with small community dishes often made from chicken fence wire.

13.4. Satellite Telecommunications Experiments Project (STEP)

STEP was carried out during 1977-79 for having a greater insight with regard to the telecommunication aspects of satellite technology. For STEP use was made of Franco-German Symphonie-1 satellite. This satellite was made available for STEP as a part of ISRO cooperation with CNES and DFVLR and was moved to 49°*E* longitude for the conduct of STEP. The project was mainly to experiment with digital satellite communications, single channels for carrier systems, radio networking and TV transmissions with several audio channels. A transportable Indian built terminal was built for use in experiment. Engineers said that the experiment effectively demonstrated the use of satellites for remote area and emergency communications. This STEP experiments were conducted jointly by ISRO and then P & T (now DOT). The vital experience gained in these experiments was instrumental for

SAT. All these experiments and experiences developed confidence among Indian planners for the launching of communication satellite in near future.

13.5. APPLE

APPLE was the first Indian experimental communications satellite launched on 19th June 1981 under an agreement with ESA, on board the third developmental flight of the European Ariane launcher. It was three axis

stabilized and weighed 650 kg. The satellite was placed into a geostationary orbit by an Indian developed apogee kick motor. Once in geostationary orbit, however, one of the two solar panels failed to deploy, although close systems management particularly thermal system meant that the satellite could be used to its intended purpose. The satellite was positioned at its assigned orbital position of 102°E longitude in early July 1981 and was decommissioned in September 1983 after completing its two year on-orbit life which was constrained by on-board propellant loading.

Apple had a microwave C band (6/4 GHz band) transponders (plus a redundant transponders). It was totally designed and fabricated and largely tested in India and had a large number of indigenous components/assemblies/subsystems. These included the main structure, the 6/4 GHz payload (with imported TWTAs), a static horizon/earth sensor, a momentum wheel, a carbon fibre antenna reflector, a solid propellant apogee motor (derived from the fourth stage of Indian SLV-3 launcher) to boost the satellite from transfer orbit to a circular, equatorial, near geosynchronous orbit etc.

With APPLE a large number of communication experiments and service demonstrations were carried out using the indigenously developed equipment. These experiments included the testing of computer communication, TDMA (Time division multiple access) communications, spread spectrum multiple access (SSMA) communication, FAX transmission and TV broadcasting. Also the social and educational experiments using the relayed TV signals were being conducted. APPLE thus gave a strong foundation to India for fixed satellite system (FSS) that led to the development of INSAT-II satellites.

13.6. The Indian National Satellite System (INSATS)

INSAT system is the result of previous experiments such as those of SITE, STEP and APPLE. It is a multipurpose and multiagency system. It transcends three vital national services such as long distance communications, TV and [illegible]

[illegible]

The overall coordination and management of the INSAT system rests with the secretaries level INSAT Coordination Committee (ICC). The Secretariat of [illegible]

[illegible] MENT.

[illegible]

satellites. The first phase of INSAT programme is also known as INSAT-I series. Unfortunately from the very beginning there were problems with INSAT-1 series satellites. The first INSAT-1 (INSAT-1A) when launched in [illegible] could not get its solar sail opened and following a series of events the

satellite was ultimately abandoned 147 days after its launch. INSAT-1B whic was launched by the US Space shuttle in Aug. 1983 had problems with it solar arrays in the beginning. It required 11 days orbit maneuvers to deplo them finally. INSAT-1C which was launched on July 22, 1988 had th problems of solar power. Its one of the two solar buses developed technica snag and is still unresolved. With this result the power availability for th spacecraft is nearly halved. INSAT 1-D was launched in the end of June 199 from USA.

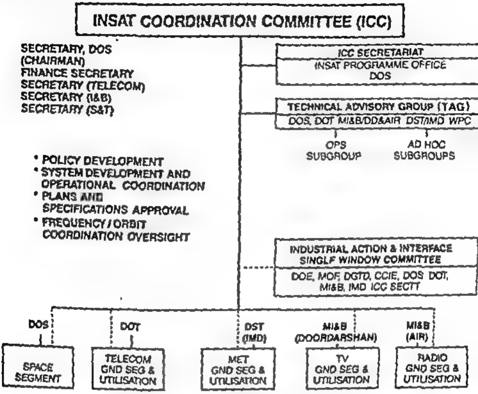


Fig. 13.1. INSAT System-Management

The second phase of INSAT systems will be developed in India itself but these will be launched by Ariance. The launching of INSAT- IIA and INSAT-IIB are scheduled for autumn 1991 and 1992. Launching will take place from Kouron Space Center in Guyana.

13.7. INSAT-1 Systems

INSAT-1 system was envisaged as a space segment consisting of two multipurpose satellites-one as the primary satellite providing all services and the other as a major path satellite providing additional fixed as well as broadcast satellite services capacities and also certain on-orbit back up capability.

Each INSAT-1 satellites weigh about 1200 Kg at lift-off and about 650 kg in geostationary orbit. The satellites gave a five panel sun tracking solar array of roughly 11. 5 sqm. generating a power of 900 watts. These satellites are designed for a minimum of 7 years life. The transfer orbit configuration and the on orbit satellite configuration of INSAT-1 satellites are given in Fig. 13.2 and 13.3 respectively.

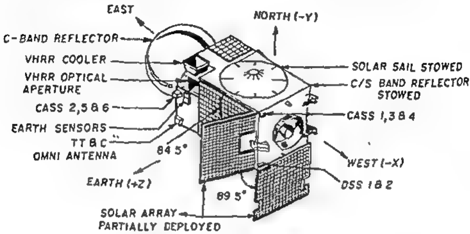


Fig 13.2. TRANSFER Orbit Configuration of INSAT-1.

In geostationary orbit under fully deployed configuration the length of INSAT-1 satellite from the tip of solar sail to the extreme end of the solar array is about 19.4 m. The INSAT-1 satellites are biased momentum three axis *stabilized spacecraft with a stability required for the meteorological imaging* mission. The satellites use an asymmetrical solar array in order to ensure an unobstructed clear field of view (FOV) into the cold space for the radiation cooler of the Very High Resolution Radiometer (VHRR) earth imaging instrument. There is a deployed solar sail used to offset solar pressure on account of the asymmetrical solar array. A magnetic torquer with a current coil placed around the pheriphery of the satellite body provides fine control. The satellite has a unified bipropellant propulsion system for transfer orbit to geostationary orbit ascent and for station and attitude maintenance. The transfer orbit to GSO ascent is also in three axis stabilized mode.

Each INSAT-1 satellite has the following 4 kind capabilities that are supposed to be in their individual 7 years life. These are (1) twelve national coverage telecommunication transponders of 36 MHz bandwidth each operating in C band with 32 dbw Effective Isotropic Radiated Power (EIRP) over the primary coverage area, (*ii*) two high power national coverage TV broadcast transponders operating in C-band uplink (earth to satellite) and *S* band downlink (satellite to earth), each capable of handling one direct broadcast (community reception) TV channel and several low level carriers for radio programme distribution with a 42 dbw EIRP over the primary coverage area. (*iii*) a very high resolution radiometer (VHRR) for meteorological earth [illegible]ng operating in visible and infrared channels with resolutions of 2.75 km

and 11 km respectively, with half hourly full earth coverage and sector scan capability and (*iv*) a data relay transponder with global receive coverage with a 402.75 MHz uplink for relay of meteorological, hydrological and oceanographic data from unattended land and ocean based automatic collection-cum transmission platforms.

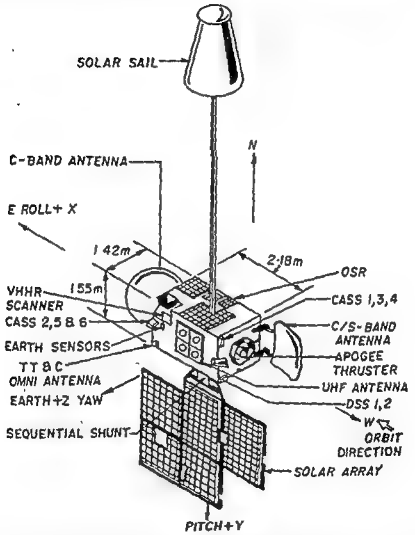


Fig 13.3. ON-Orbit Satellite Configuration of INSAT-1.

The INSAT MCF is located at Hassan and it consists of 2 satellites control Earth Stations (one with a 14 m fully steerable antenna and the other with a 7.5 m limited steerability antenna). In addition the MCF has an additional

14 m fully steerable antenna, INSAT-1 satellite control centre (SSC) with associated TT & C equipment, on-orbit checkout equipment, computer facilities and auxiliary power (including a no-break component). For further and expert monitoring of spacecraft health and formulation of manouver, satellite telemetry data are also available at INSAT-1 Space Segment Project Office (SSPO) and the ISRO Satellite Centre ISAC.

13.8. INSAT-1 Utilization

The INSAT-1 utilization as proposed and carried out by various national agencies are as per chart shown in Fig. 13.4. These services are proposed

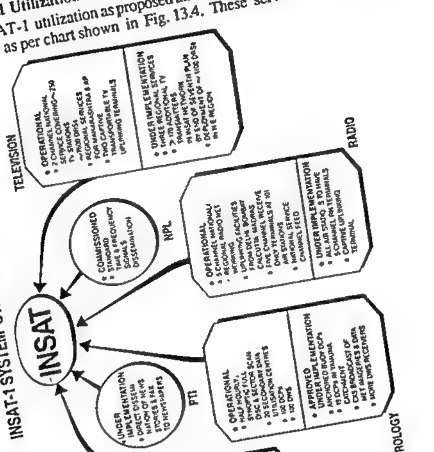
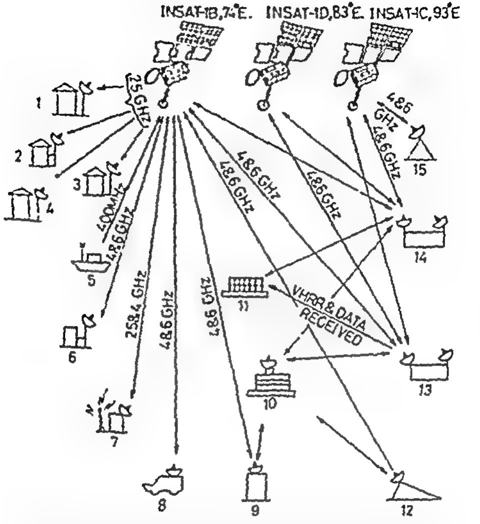


Fig. 13.4. INSAT-1 System Uulization

carried out by the INSAT-1 systems arrangement given in Fig. 13.5. The munications component of the two satellite INSAT - 1 space-segment



1. News and Facsimile Dissemination 2 Disaster Warning 3 Meterological Data, Fax and Imageries Dissemination 4. Direct Broadcasting to Rural Communities (TV) 5. Metero-

Fig. 13.5. INSAT-1 System Concept

is designed to provide over 8000 two way long-distance telephone circuits potentially accessible from any part of India, even the remotest without regard to intervening terrain and terrestrial distance. According to a report based on 1988 some 48 telecommunications earth stations were working in telecommunication network using INSAT to provide long distance communication facilities on over 80 routes. INSAT-1 telecommunication ground segment and trunk routes as on March 1988 are shown in Fig. 13.6 and 13.7 respectively.

Fig. 13 6. INSAT-1 Telecommunications Ground Segment as of March-1988

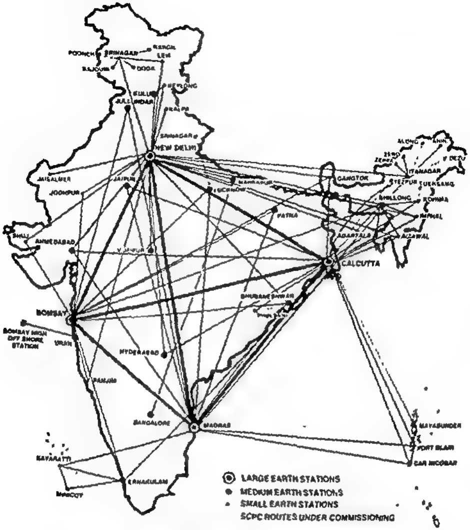


Fig. 13.7. INSAT-1 Telecommunications Trunk Routes as of March 1988.

ONC [illegible]
com[illegible]
Centre (NIC)'s satellite based NICNET using SSMA is being completed. NICNET have adopted a SSMA/CDMA type very small aperture terminals [illegible]

Fig. 13 8. Ground Segment of INSAT Radio Networking Scheme as of March 1988.

either 1W (for 1200bps) or 5W (for 9600bps) In NICNET any micro earth station can access any other microearth station in the network by dialing the number of the earth station. Each of the microearth station has been assigned a unique code. By the time of INSAT- 1D comes up NICNET is expected to have ninety microearth stations at remote sites including Kavarati, Dharmapuri, Ooty and Bhilwara.

Satellite based rural telegraph network (SBRTN) for INSAT is as that shown in Fig. 13.10. The meteorological component of the INSAT system ... weather ... top tem- ... well as

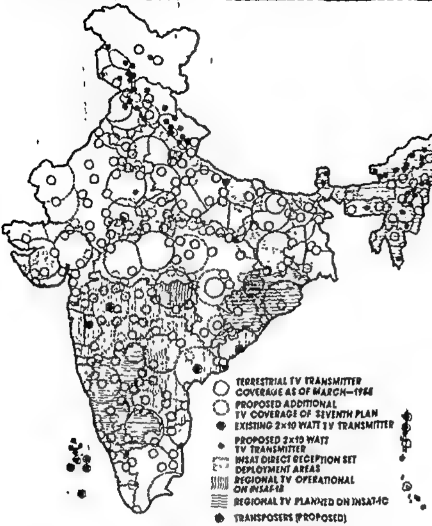


Fig. 13.9. Expected TV Coverage of India by 1990

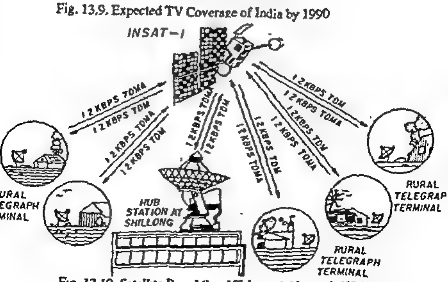


Fig. 13.10. Satellite Based Rural Telegraph Network (SBRTN)

adjoining land and sea areas, (*ii*) collection and transmission of meteorological, hydrological and ocenographic data from unattended remote platforms, (*iii*) timely warnings of possible disasters from cyclones, floods, storms etc and (*iv*) dissemination of meteorological information including processed images of weather systems to the forecasting offices. The enhanced meteorological data provided by the INSAT benefits Agriculture, Aviation, Ports and Shipping, hydro-meteorological and flood forecasting services/sectors.

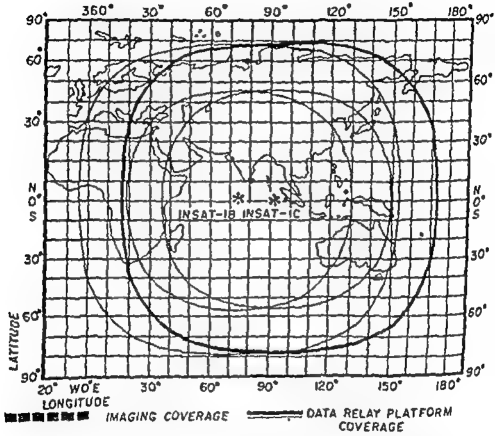


Fig. 13.11. Imaging and Data Relay Platform Coverage of INSAT-1 System

The Imaging coverage and Data Relay Platform coverage of INSAT-1 [illegible]

satellites and disseminating the processed data to users. The meteorological data transmitted by INSAT-1B are first received at Delhi Earth Station (Sikandarabad of Bulandshar District in U. P.) about 60 kms from Delhi from where they are transmitted to NDUC over a microwave link.

Fig. 13.12. INSAT-1 Meterological Ground Segment as of March 1988

The INSAT Disaster Warning System (DWS) Concept is shown in Fig. 13.13. This scheme has been initially implemented on an experimental basis in selected coastal areas of southern Andhra Pradesh and Northern Tamil Nadu. The warning messages originating from the Area Cyclone Warning Centre, Madras are transmitted to INSAT-1B from the Madras Earth Station of DOT. A S Band transponders on board INSAT-1B receives and relays back these signals for reception by Disaster Warning receivers deployed in southern

and November 1987.

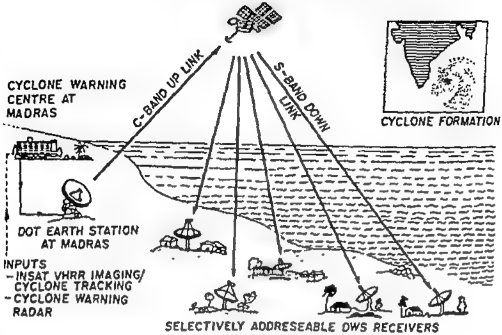


Fig 13.13. Disaster Warning System Concept

13.9. INSAT-II

As already mentioned in the early 1990's the foreign procured and for-

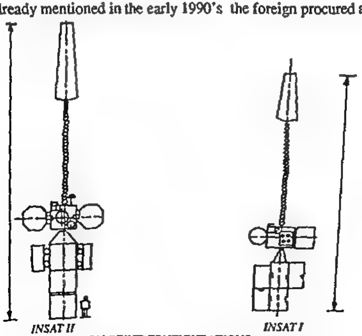


Fig. 13 14. Comparison Between INSAT-I and INSAT-II Space craft

eign launched INSAT-1 spacecraft will be gradually replaced by indigenously developed second generation (INSAT-II) spacecraft which will be launched from India by the Indian Geostationary Satellite Launch Vehicle (GSLV). However, at the moment it has been decided by the authorities to get these satellites launched by ESA Ariane. Fig. 13.14 shows a basic comparison of INSAT-II and INSAT-I system whereas Table 13.2 gives these differences in some detail.

Table 13.2. Comaprison of INSAT I and INSAT II

	INSAT-I	*INSAT-II*
Length (m : fully deployed)	- 19m	- 23m
Dry Mass (kg)	- 550 kg	- 860 kg
EOL minimum power (W)	- 930 W	- 1180 W
Payload complement (in each spacecraft)		
C band FSS transponder channels	12 (32 dbW EOC) Functional channel redundancy (10/12)	18 total-16 (32 dbW EOC) and 2 (34 dbW EOC). Functional redundancy in conventional C band (10/12) and 3:2 in output stages for 6 extended C band transponder channels
S band high power BSS channels	2 (42 dbW EOC) 3/2 TWTA redundancy	2 (42 dbW EOC) 3:2 TWTA redundancy
VHRR and DRT	2.75 Kms visible and 11 Kms IR resolution; 2·1 redundancy in VHRR electronics, x'mtr and DRT	VHRR (Imporved resolution)-2 Kms visible and 8 Kms IR resolution; S/C level VHRR and DRT redundancy as in INSAT-1 6 dB improvement in VHRR x'mtr eirp
406 MHz S & R transponder		Included
Eclipse operating capability for payload (in each s/c ; equivalent at EOL)	150 W (aprox.)	340 W (approx.)
Omni-TT & C	Yes, uses FSS transponder channel Nos. 4 and 5 TWTAs	An additional antenna added for improved coverage. Independent output stages, FSS channels not tied down
Deployments:		
Solar array	Asymmetrical; involves [illegible]iaxial deployments, [illegible]tual deployment in transfer orbit	Asymmetrical; Accordion type; simpler deployments, no partial deployment in transfer orbit

	INSAT-I	INSAT-II
Antenna	Two deployables on East and West faces. All 6 GHz receive functions on East face depoloyable antenna	Two deployables on East and West faces but a third fixed antenna added for all 6 GHz receive and VHRR and DRT transmit functions. Greater mission functions saving in case of depoloyment anomalies.

The space segment concept of INSAT II is shown in Fig. 13.15. INSAT II is to be used by various agencies for a variety of services. Main users are DOT, IMD, AIR and Doordarshan. The initial all up INSAT-II space segment is to have three multipurpose satellites-two of them collocated at the primary orbital position and one at the major path orbital position. The two spacecraft at the primary orbital position are to be collocated and station-kept in such a manner that they appear as in single large capacity spacecraft in terms of their total. Fixed Satellite Service (FSS) capacities in conventional c-and upper extended C band by use of orthogonal polarizations. Though multipurpose and somewhat similar in configuration to INSAT-1 spacecraft, each INSAT-II spacecraft has a considerably larger FSS pay load complement and a higher resolution meteorological imaging (VHRR) instrument than an INSAT-1 spacecraft.

The overall capacity requirements for INSAT-II are as follows: (*i*) *Fixed Satellite Services* Transponders for telecommunications requiring 34 dbW EIRP in C-band and Extended C-band; specialized telecommunications requirement for dedicated user networks using roof top terminal calling for higher EIRP (36 dbW) in extended C-band with frequency allocations such that they are clear of interference from and into terrestrial system; transponders in the C band and extended C-band for nation wide distribution of TV programme for rebroadcast, (*ii*) *Broadcast Satellite Services* : The requirement for broadcast satellite services for direct TV broadcast to community reception includes four operating S-band transponders with an EIRP of 42 dbW over the primary coverage area, (*iii*) *Radio Networking and Other S- Band Point-to-multi-Point Services* : this requirement is to cater to at least 32 low level carriers for distribution of radio signals for re-broadcast as well as point-to-multipoint applications such as disaster warning service, standard time and frequency synchronization, meteorological data distribution etc; (*iv*) *Meteorological Services* : A very high resolution radiometer (VHRR) for coverage of the designated area (extended angle of 14 degrees North to South and 20 degrees East to West) with a resolution of 2 km in visible and 8km in infrared channels; facility for transmission of processed meteorological data via satellites; a 400 MHz uplink and 4GHz donwlink data relay transponders for access by low cost unattended data collection platforms; a disaster warning

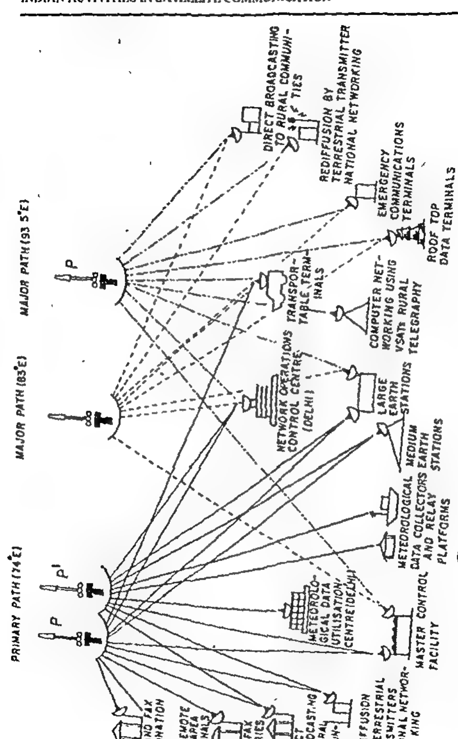


Fig. 13.15. INSAT-II Space Segment Concept

service using low level RN type carriers to address selected individual receivers in disaster prone areas and (v) *Satellite Aided Search and Rescue (SAS&R)* : This requires a provision of 406 MHz uplink and a 4GHz downlink relay electronics to provide geostationary alert function in the overall Indian satellite aided search and rescue programme and to form a part of International COSPAS-SARSAT system.

For the realisation of INSAT-II system, Govt. of India had approved in 1985 the INSAT-II testsatellite project which envisaged design development and test of two INSAT-II satellites. First INSAT- II test satellite INSAT-IIA is scheduled for launch in the last quarter of 1991 and the second INSAT-IIB a year thereafter by Ariane. For the INSAT-II programme, the INSAT Master Control facility (MCF) at Hassan is being augmented. Two 11 m Ø satellite control earth stations and an INSAT-II control center (SSC) are being added together with VHRR on-orbit test and check out facilities etc.

13.10. Small Earth Stations in India

Alongwith the master earth stations for INTELSAT, INMARSAT, LANDSAT, INSAT, IRS-IA, there are several small earth stations in India

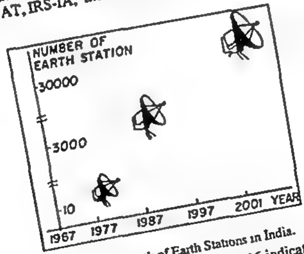


Fig. 13.16. Growth of Earth Stations in India.

and the number is increasing day by day. Fig. 13.16 indicates the growth of earth stations in India since 1967 onwards. It is hoped that by the end of the present century there will be several thousands of such small earth stations in India which are used for a variety of purposes. Table 13.3 indicates the typical parameters of small earth stations used in India. Table 13.4 gives typical link budget of small earth stations working in compounded FM-SCPC-FDMA Mode. Table 13.5 shows the cost of these small earth stations alongwith the cost of testing equipments (there are 1987 quote). In India initially these earth station equipment were imported mainly from USA. Now these are indigenously manufactured in India. Two R & D units - Telecommunications Research centre of the Dot and SAC of ISRO have been involved with

the indigenous development of earth station equipment. A number of manufacturing units have been associated with the production and supply of equipment including antennas of various sizes, HPAs, LNAs, CFM-SCPC equipment, echo-suppressers, multiplex equipment, and uninterrupted power supply (UPS) equipment.

Table 13.3. Typical Parameters of Small Earth Stations in India

Item	*Subitems*	*Parameters*
System Performance	G/T S/N	19.7 dB/K 50.0 dB
Antenna	Size Category Mount Tracking at 6 GHz Receive gain at 4 GHz	4.5 M Dia Cassegrain feed X-Y Manual 42.5 dB
Transmitter	Amplifier type output power	FET Amplifier 20 Watts
Receiver	Amplifier type Noise Temperature	Uncooled FET Amplifier 90 K
Mode of Communication	Modulation Access Assignment	CFM-SCPC FDMA Preassigned and Demand Assignment

Table 13.4. Typical Link Budget of Small Earth Stations Working in Companded FM-SCPC-FDMA MODE

Parameters	*Small Earth Station (19.7 dB/K) to Master Earth Station (31.7 dB/K)*	*Master Earth Station (31.7 dB/K) to Small Earth Station (19.7 dB/K)*	*Unit*
1. *General*			
(*a*) Type of carrier	CFM-SCPC	CFM-SCPC	
(*b*) Connectivity	4.5-11.0	11.0-4.5	m
(*c*) RF Spacing	45	45	KHz
(*d*) Noise Bandwidth	20	20	KHz
2. (*a*) Earth Station EIRP per channel	36.8	45.8	dbW
(*b*) Path loss	200.0	200.0	dB
(*c*) Satellite G/T	-6.0	-5.0	dB/K
(*d*) Earth Station	1.5	0.0	dB

	Tracking Error			
	(e) Noise Bandwidth	43.0	43.0	dB
	(f) Boltzmann Constant	-228.6	-228.6	dbW/KHz
	(g) C/N UPLINK	14.9	26.4	dB
	(h) C/N/IM	18.0	18.0	dB
3	(a) Satellite EIRP per channel	0.8	9.8	dbW
	(b) Path Loss	196.0	196.0	dB
	(c) Earth Station G/T	31.7	19.7	dB/K
	(d) Earth Station Tracking Error	Nil	-1.5	dB
	(e) Contour Loss	-0.1	-4.0	dB
	(f) Boltzmann Constant	-228.0	-228.6	dbW/KHz
	(g) Noise Bandwidth	43.0	43.0	dB
	(h) C/N/DNLINK	21.1	13.6	dB
4.	(a) C/N/total	12.5	12.1	dB
	(b) C/N/Threshold	8.0	8.0	dB
	(c) Margin	4.5	4.1	dB

Table 13.5. Typical Equipment Cost of Small Earth Station (with Indian Equipment)

	Equipment	*Quantity*	*Price in Indian Rupees*
1	4.5 m dia cassegrain feed antenna	1	375,000
2.	20 WHPA in redundant configuration with auto switch over facility	1	900,000
3.	90°/K LNA in redundant configuration with auto switch facility	1	425,000
4	UP/Down converter in redundant configuration with common equipment for SCPC subsystem	1	1800,000
5	SCPC Modems (preassigned)	4	520,000
6.	Power Plant	1	200,000
		Total =	4220,000
7	Testing Instruments (imported) : Dual Beam Oscilloscopes RF Spectrum Analyzer, Transmission Test Set, Frequency Counter, Power Meter		250,000
		Grand Total =	4470,000
		=	US $ 350,000

Indian Telephone Industries has now a days started manufacturing low-cost satellite communication equipment for transmission using a special technology called Spread Spectrum Multiple Access (SSMA). ITI Equatorial SatCom Ltd, a joint venture of ITI with the Equatorial Pacific International Company of USA are going to manufacture these low cost earth stations which are supposed to revolutionize the data transmission. These microearth stations operating in a satellite based network of their own offer a cost solution of thin route data communication between central host computers and a large number of remote sites. The equatorial network is expected to upgrade Government and private sector telecommunications infrastructure at a low cost

13.11. Indian Remote Sensing Satellite and Data Utilization Of Landsat

In India surveying and management of natural resources have been identified as a major national need. Following path finder studies with multi-spectral cameras, Side Looking Airborn Radar (SLAR) and other instruments, India created the National Remote Sensing Agency (NRSA) at Secundrabad in Andhra Pradesh in 1975 to centralize the effort. The NRSA was transferred to DOS in 1980. Further an earth station was set up at Hyderabad in 1979 for direct reception of LANDSAT data (LANDSAT 2 and 3 to start with). The station was later upgraded to receive data from subsequent satellite with improved sensors. The data received offers full coverage of India. The cost of the LANDSAT reception including processing costed NRSA about Rs. 25 mn in 1979.

Initially following projects were assigned under LANDSAT data products generation: (*i*) Snow-melt run off prediction 1982 (Sutlej catchment), (*ii*) Soil survey-Man and Jobat area (MP), (*iii*) Lower Barak river watershed Survey in Assam, (*iv*) Snow-melt run off prediction for Alakananda and Bhagirathi rivers (1981, 1982, 1983), (*v*) Hydrologic characteristics of river basins in Punjab, (*vi*) Survey of Madras and its environments for Land use and ground potential, (*vii*) Geological and geomorphologial survey of western Rajasthan, (*viii*) Mapping of water boards for AP Rajasthan, Karnataka and U. P. , (*ix*) Groundwater potential maps of Hyderabad and Bangalore, (*x*) National bracieish water mapping-Tamil Nadu Coast, (*xi*) mapping of forest cover in India, (*xii*) wasteland mapping of India (in 1 million scale), (*xiii*) integrated land and water resources survey of two districts (demonstration) and (*xiv*) mapping of wastelands in 182 critically affected districts in India in 1:50,000 scale (in progress). Since May 1984 TM data (thematic mapper data) are also received from Landsat-5 and from 1985 end routine data supply also started.

India also started for its own Earth observation and then remote sensing satellite since 1979 onwards by launching Bhaskara on 7th June '79 by a Soviet C-1 rocket. Then on 20th Nov 1981 Bhaskara-2 was launched again from Soviet. Bhaskaras were precursors to the IRS-1A that was launched on 17th March 1988. It is the largest satellite developed in India. It spans 11 meters with both solar panels deployed and weighs 975 Kg at launch. The main structure consists of a central load bearing cylinder with four vertical and two

orizontal honeycomb panels which provide the necessary mounting areas and space or on board subsystem modules. The sensor payloads of IRS-1A include two pushbroom cameras (LISS-II) of 36. 25m resolution employing linear charge coupled devices (CCD). Each of the camera systems images in four spectral bands in the visible and near infrared region, using four separate lens assemblies, each with a CCD detector array of 2048 elements. The pushbroom scan mode operates in such a way that the linear detector array is used to image the scene in the cross track direction of the spacecraft motion. Table 13. 6 gives these spectral bands of IRS-1A.

Table 13.6. Spectral Bands of IRS-1A

Band	*Spectral range in microns*	*Remarks*
1	0.45 - 0.52	Coastal environment studies chlorophyll absorption region
2.	0.52 - 0.59	Gren vegetation useful for discrimination of rocks and soil for their iron content
3.	0.62 - 0.68	Strong correlation with cholrophyll absorption in vegetation, discrimination of soils and geological boundaries
4.	0.77 - 0.86	Sensitive to green bio-mass opaque to water resulting in high contrast with vegetation

Two solar arrays each 4 meters long and the solar array drive and powe transformer assemblies (SADAPTA), mounted on two sides of the body along the pitch axis, provide life power of 695 W. Besides these, there are two nickel-cadmium rechargeable batteries of 40AH capacity each. These provide power when during the eclipse the solar energy is cutoff from the satellite. IRS-1A has a telementry system operating in the S-band for monitoring the health of the satellite. The tracking system is built around the S-band to determine its correct position. The command system is able to carry around 511 on off commands, though it will require only 350 commands, for the operations. The data from the satellite is converted into a number of dat products such as films, microfiche, computer compatible tapes (CCT), fals colour composites (FCC) and colour as well as black and white prints. There are five different levels of processing, namely, level O or quick look product, level 1 or browse product, level 2 or standard product, level 3 or precision product and level 4 or special product. Thus IRS-1A sweeps every strip of India's landmass and so apart from preventing an ecological and environmental disaster IRS-1A has opened many locked doors and provides information in interpretable data for Indian scientists on natural resources and overall health of the subcontinent. IRS - 1A's life span is about 3 years (1988 - 91). IRS -

IEM is going to cover the period between 1990-92. This would help to have correlated and continuous supply of data on the study of the health of Indian sub continent and what are contained underneath.

India is going to launch its own microwave remote sensing satellite by 1993-94. It would be of importance to mention here that when IRS-1A was launched from USSR, two regional remote sensing services (RRSSC) were becoming operational. One was at Bangalore and the other at Dehradun. Since the launch of IRS-1A, a chain of RRSSCs has been setup for digital interactive analysis of remotely sensed data, a major element of the national natural resource management system (NNRMS). Three more RRSSCs have been opened at Nagpur, Jodhpur and Kharagpur. About 20 central government departments and agencies apart from states and union territories are involved in the operations of NNRMS. One major element in NNRMS is the establishment and operation of the interactive computer system to enable digital analysis of remotely sensed data by 300 user units.

13.12. India's Participation in other International Communications Satellite Systems

Before INSATs India was already using INTELSAT services. India is also founder member of INMARSAT. There are plans for the 1990's to set up mobile satellite communication services for use by both business and Government agencies including Indian Railways. Standard C ship Earth station that has been introduced by INMARSAT for small ships, aircraft and land vehicle is being developed by ISRO and the immediately demand for this terminal is expected to be around 3500. Another type of mobile service, radio determination or position fixing is also attracting attention. Development of Global positioning system (GPs) receiver is taken up for introducing satellite navigation in India.

In August 1986, DOS has concluded a Memorandum of Understanding (MOU) with the GEOSTAR Corporation of USA for a joint feasibility study for implementing a Radio Determination Satellite Service (RDSS). Fig. 13.17 indicates this RDSS system concept in Indian Ocean region. A joint study with the European Space Agency (ESA) on definition of an international civilian global satellite navigation (SATNAV) system has also made considerable progress. ISRO has also been providing the principal technical support for the active Indian participation in International Civil Aviation Organization (ICAO)'s Future Air Navigation Systems (FANS) committee which is responsible for defining the basic functional specifications/characteristics for future satellite communication and navigation systems/services and allied matters for civil aviation purposes. India is getting involved in early demonstration/testing phase of aeronautical satellite communication.

Another area in which India is having International Cooperation in satellite communication is Satellite Based Search and Rescue Operations Ser-

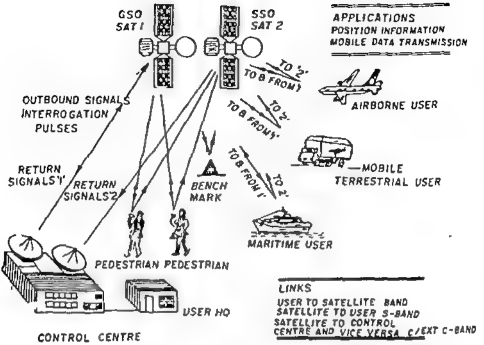


Fig. 13 17. RDSS System Concept

vice. The Govt. of India has decided to promote, participate in and contribute to the development of international satellite-aided search and rescue sys-

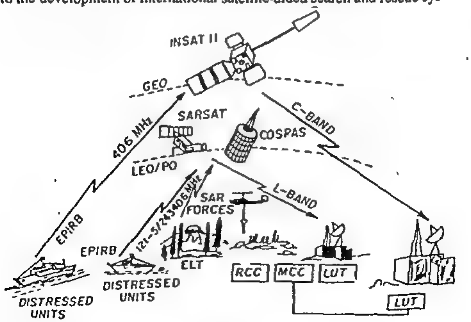


Fig. 13.18. Satellite-aided Search and Rescue.

tem (SAS & R) for maritime, airborne and land distress alert detection and position location. This national (SAS & R) is a multi pronged plan involving (*i*) use of the existing USA-USSR-France and Canada COSPAS-SARSAT Space Segment and establishment of a Local User Terminal (LUT) in India, (*ii*) indigenous development of 406 MHz emergency locator beacons (ELBs , (*iii*) testing of a sample of existing 121.5 and 243 MHz ELBs in inventory and under indigenous production for COSPAS-SARSAT compatibility, (*iv*) Contribution to the future international SAS&R space segment by carriage of SAS&R payloads on future Indian satellites and (*v*) securing a first-level participation for India in the international SAS&R system. Fig. 13.18 indicates this SAS&R scheme.

13.13. Spin-Offs to Industries

Indian participation in communication satellite programme and other space technology activities has led ISRO to accumulate a wealth of advanced technology. Infact it is an internationally recognized fact that technological and managerial demands of space projects such as miniaturization, automation, weight and volume optimization, use of new materials, quality and reliability engineering practices, system engineering and project management continue to provide a unique standard with spinoffs for innummerable industries and markets. The know-how for products and processes primarily developed for programmes and projects in space science, technology and applications can be applied elsewhere and in ways other than originally intended for the greater benefit of industries.

ISRO's ties with industries include technology transfer from the space programme to industries, technological consultancy to industry by ISRO, utilization of industry's own technology potential and expertise by the space programme and procurement of goods and services from industry by ISRO. Under technological consultancy services, over 60 consultancy projects have been taken up and several are in pipeline. In Satcom field consultancy for low power TV transmitter has been very important. The major industrial sectors to which ISRO's technology have been transferred are special chemicals, polymers, materials and composite, electronics telecommunications and TV systems, precision electro-mechanical, opto- mechanical and electro-optic instruments, microprocessor based systems; special purpose machines, com- [illegible]

Space Electronics Division (SED) of Bharat Electronics Ltd is exclusively devoted to space programmes. Till 1987, 133 distinct technologies have been licensed by ISRO and National Remote Sensing Agency (NRSA) of Department of Space. The technologies of equipments, systems and software transferred from Space Application Centres are shown in Fig. 13.19.

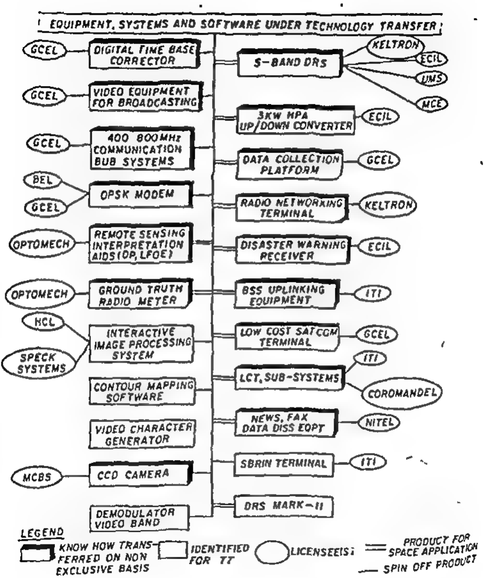


Fig. 13 19 Equipment Systems & Software Under Technology Transfer of SAC

With the above immense spin offs to industries the Govt. of India has accepted, in principle, a proposal by ISRO for setting up a separate corporate front to interfere with the Indian space activities. According to Director of Technology Transfer and Cooperation at Department of Space, the proposed company would not just be for technology transfer but would also play an active role in high tech vendor/entrepreneur development and in providing services such as exports promotion for licenses. However, the modalities for the proposed company had yet to be worked out. Since the eight and ninth plans envisage a tremendous growth in the space programme and space applications, the need of above company is getting essential as there would be much involvement with other industries. At the moment (report year 1988 based) ISRO had 500 indigenous industrial partners, 200 of them doing critical high-tech jobs, as compared to about 60 doing such critical jobs three years ago.

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FOURTEEN

Laser Satellite Communication

14.1. Introduction

Laser satellite communication involves transmission at frequencies in the 10^{14} HZ(optical) range which is around seven or eight orders of magnitude higher than the radio frequency (RF) systems. Transmission at such frequencies provides three main advantages, namely the greater bandwidth, smaller beam divergence angles and smaller antennas. Infact communication with lasers is being used now a days in three modes of communication. These are aerial laser-beam communications, fibre optic communication and optical computers. In aerial laser beam communications, data and images are transmitted through the atmosphere using low power laser beams. It has the advantage that it is almost impossible to jam by known means. Moreover because of the extremely widebandwidth of laser radiation, upto 10 discrete conversions can be executed simultaneously. Such an aerial laser beam communications is, however, completely weather dependent. On a clear day a laser beam can be transmitted several miles but when atmospheric condit[illegible]

[illegible]

information per second [illegible]

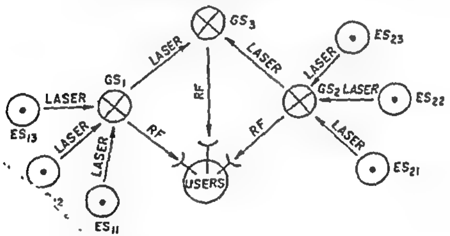
[illegible]

equivalent sized electronic circuit. There is no pr[illegible] cross link analysis given in parallel channels. [illegible] atmosphere are considered to [illegible] space between two satellites).

Being atmospheric dependent, laser com[illegible] used for uplink and downlink used for communication between earth statio[illegible] between two satellites is optical However, it is quite suitable for communica[illegible] when the satellite receives uplink, [illegible] carrier bandwidth onto the optical

selves or deep space communication. A typical example for such a cross satellite laser communication is as that shown in Fig. 14.1. Here GSs are the geosynchronous satellites whereas ESs are some other satellites (e.g. earth observation or special purpose satellites). These ESs communicate to GSs with laser communication and eventually the GSs communicate with the earth station through RF microwave communication. The optical transmitters and receiver packages are smaller and lighter than the equivalent HF microwave subsystems. This helps in reducing the spacecraft cost and weight. For deep space communication where the planets desired to be communicated with the earth are quite far, the received signals are very weak and then this intersatellite laser communication solves problem. Here the deep space-craft will have deep space optical link with a geosynchronous satellite which provides microwave link to the earth station. Conclusively, therefore the laser satellite communication serves for intersatellite communications and here the analysis of cross optical-link is necessary.

GSs = Geosynchronous Satellites
ESs = Earth Observation Satellites or any other Deep Space Satellite



'. Example of Laser Satellite Communication

downlink beam appears to be about 10 μ radians larger. In clear days the mixing of warm and cool atmospheric strata produce turbulence which may interact with impinging light [illegible] the impinging beam. This c [illegible] steering) and create optical po [illegible] introduces loss in beam front coherence which means that two points on the beam front would be no longer in phase. This affects both the direct and hetrodyne optical detection systems.

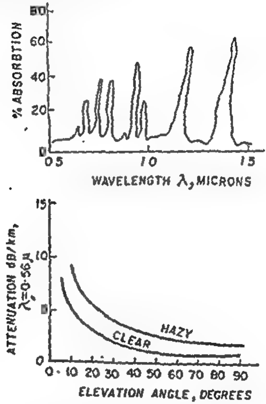


Fig. 14.2. Atmospheric Attenuation
(a) as a function of optical Wavelength,
(b) as a function of elevation angle

(b) *Complete Link Analysis* : Satellite optical cross link analysis given [illegible]

transmission to the satellite and the crosslink between two satellites is optical link that uses direct detection system. Thus when the satellite receives uplink, it directly intensity modulates the uplink carrier bandwidth onto the optical

[illegible] it is essential that the upper limit of the uplink [illegible] or bandwidth otherwise [illegible] before laser modulation. [illegible] ented as

$$s(t) = u(t) + n_u(t) \qquad \ldots(14.1)$$

where $u(t)$ is the uplink carrier and $n_u(t)$ is the uplink noise and interference. Since the laser power at the optical receiver is intensity modulated so

$$P(t) = P_r (1 + \beta s(t)) \qquad \ldots(14.2)$$

where P_r is the average power and β is the intensity modulation index ($\beta \leq 1$). *The receiving satellite receives the signal of Eq(14.2) by photodetecting it.* The photodetector detects this intensity modulatd signal as

$$R\,[\beta P_r s(t)] = R\,\beta P_r [u(t) + n_u(t)] \qquad \ldots(14.3)$$

where R *is the photodetector responsivity.* The photodetected waveform that is actually of the uplink frequency is then translated to the downlink frequency which is then power amplified and transmitted to the receiving earth station. *If* P_t *represents the available downlink satellite power,* α_s and α_n *as the signal* and noise suppressions and L as the net downlink losses, then the recovered downlink carrier power may be expressed as

$$P_s = \alpha_s^2 P_t [(R\,\beta P_r)^2 P_{cu}] . L \qquad \ldots(14.4)$$

where P_{cu} is the uplink power of $u(t)$ in Eq(14.1). Also the total downlink *retransmitted noise power (uplink plus total photodetector noise) can be* expressed as

$$P_{nd} = \alpha_n^2 P_t [(R\,P_r\,\beta)^2 P_{nu} + P_{PD}]\,L \qquad \ldots(14.5)$$

[illegible] P_{nu} [illegible] uplink noise power and P_{nd} is the combined photodetector [illegible] In [illegible] g downlink signal to noise ratio [illegible] k transmission is finally

$$(C/N)_T = \frac{P_s}{P_{nu} + P_{nd}} \qquad \ldots(14.6)$$

Defining $$(C/N)_u = \frac{P_{cu}}{P_{nu}} \qquad \ldots(14.6)$$

$$(C/N)_{op} = \frac{P_s}{P_{PD}} \qquad \ldots(14.8)$$

$$(C/N)_r \approx \frac{L P_t \alpha_s^2}{P_{nd}} \qquad ...(14.9)$$

and

$$\alpha_s^2 = \left[1 + \frac{1}{(C/N)_{op}}\right]^{-1} \qquad ...(14.10)$$

one may write Eq (14.6) in the form as

$$(C/N)_T = [(C/N)_u^{-1} + (C/N)_{op}^{-1} + (C/N)_r^{-1}] \qquad ...(14.11)$$

where all (C/N) ratios refer to the uplink satellite carrier bandwidth. Eq. (14.11) when compared with the case of analog satellite link formula of Eq. (2.29) shows that here the term due to the presence of optical crosslink is simply added and also the usual downlink $(C/N)_r$ term is modified. This modification is due to the satellite amplifier carrier suppression effects that are now determined by the optical link. In Eq (14.11) it can be seen that the weaker of three link terms would control the overall performance. Thus if $(C/N)_{op}$ is maintained at a high value (higher than that of uplink and downlink values) the satellite communication system would remain *transparent* to the optics. For digital satellite communication one would need (E_b/N_o) as given in Eq. (4.22) in terms of (C/N_o). Here one needs two more information, the information bit rate and the system link margin (for degradation). This margin is usually taken for satellite cross links as one or two dB. The required error probability in digital satellite communication is of the order of 10^{-5}.

14.3. Optical Satellite Link Transmitter

Basically the transmitter part of an optical satellite link consists of a laser source, modulator and antenna alongwith some data handling electronics. Infact this optical transmitter is quite analogous to its RF counterpart.

Laser Source : A variety of laser sources may be used for optical satellite communication systems. These may be gas lasers, solid-state lasers and semi-conductor lasers. Selection of laser source is dependent upon a number of factors that include link range, propagation medium, data rate and platform limitations. Table 14.1 gives a brief summary of the various laser sources commonly used in optical satellite communication system. Lasers extend from high powered, low efficiency, bulky devices to the smaller light weight GaAs(gallium arsenide) solid state diodes. Semiconductor lasers are also being used such as AlGaAs and InGaAsP. The AlGaAs lasers emit reliably between 0.78 and 0.86 μ m and InGaAsP lasers emit between 1.2 and 1.65 μ m.

The satellite crosslink uses preferably the laser diodes because of their light weight. But since these are low powered devices (output power on the

asers and Nd: YAG laser were also successfully tried. But with the development in the technology, it is now confirmed that the sèmiconductor lasers re the ideal light source for optical communication in space communication ue to their small size and weight, high efficiency and reliability. In addition emiconductor lasers are easily modulated by direct current injection. The [illegible] ptics technology has developed the coherent combining, thus increasing the ower in the beam while decreasing the beam divergence. Monolithically abricated laser array designs have further solved the above beam divergence roblem.

Table 14.1 Laser Sources Commonly Used in Satellite Optical Communication

Laser types	*Wavelength*	*Average power output*	*Efficiency*	*Characteristics*
d-YAG (neo-ymium ittrium, uminium arnet)	1.06 μ	0.5-1 W	0.5-1%	Requires elaborate modulation equipment, diode or solar pumping. Has 10,000 life hours. Frequency doubling loses efficiency.
ystal	0.532 μ	100 MW	0.5 -1%	
aAs (Gallium rsenide,solid ate)	0.8-0.9 μ	40 MW	5-10%	Life hours 50000, reliable, small, rugged, compact, directly and easily modulated, easily combined into arrays, Nanosecond pulsing.
O_2 (gas lasers) rbon dioxide	10 6 μ	1-2 W	10-15%	Life hours 20,000 used in IR range, Detector are poor, uses a discharge tube, modulation is difficult.
eNe (Helium eon)	0.63 μ	10 MW	1%	Life hours 50,000. Requires external modulation, Has gas tube, is power limited and is inefficient.

Modulators : In laser space communication the most preferable modution is direct intensity modulation. Various methods that can be used to odulate laser can be as that given in Table 14.2. These are the direct odulation methods. Here the driving current of the laser is varied in cordance with the type of modulation required. Modulation rates of about

1 Gbit/s with the laser diodes have also been achieved. Direct modulation of light *via* the sources drive current causes dynamic effects on the emitted spectrum like those of changes in the peak wavelength and in laser modes. The latter effect is particularly strong in monomode lasers.

Table 14.2. Various Optical (Laser) Modulation Methods

Modulation Type	*Analog*	*Pulse*	*Digital*
Information Signal	Time Continuous	Time Continuous or sampled	Time Sampling
Carrier parameter (amplitude, intensity, frequency, phase or polarization)	Continuous	Continuous or quantized	Quantized and coded
Example	Intensity modulation	Pulse Intensity modulation	Pulse Code modulation, Intensity Modulation

Other light sources *e.g.* gas lasers may not be capable of being modulated at all. This makes external modulators attractive. Solid state lasers such as Nd:YAG which are capable of achieving a modulation rate of more than 1Gbit/s also require external modulators. The external modulators utilize miniature guiding structures (integrated optics) and operate with much less modulating power. A variety of effects such as electro-optic, acoustic optic, magneto-optic have been employed in a number of configurations (channel waveguides, planar wave guides etc) to realize modulation.

Antennas : As with the RF communication systems, the laser satellite communication systems also utilize antennas to direct the transmitted energy. Here the antennas are nothing more than the conventional design telescopes where the size and geometry are dictated by the wavelength and system requirements. Thus the optical satellite communication system requires narrow light beamwidths (fractions of a degree) instead of antenna gain patterns of several degrees needed by rf systems. They also have lensing system for beam transmission and focussing instead of rf antennas

The concept and some elementary mathematics concerned with the laser optics can be studied with the help of Fig. 14.3. Here a laser source generates a light wave which is focussed into an optical beam and then propagates a distance z over a free space path to a collecting area A_r. It should be noted that the focussed beams are usually modelled as having circular symmetric beam patterns with beamwidth.

$$\phi_b = \frac{\lambda}{d_t} \qquad \text{...(14.}$$

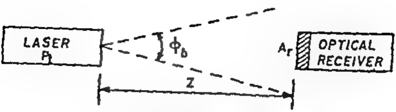


Fig. 14.3. Optic Antenna Transmission

where λ is the wavelength of the laser light and d_t is the diameter of t transmitting optics of the laser. In a typical example of visible optical ran $\lambda = 1, \mu = 10^{-6}$ meter and a transmitting lens of only 6 inches (0.15 meter), beam of about 10 microradian will be produced ($1° = 17.5$) milliradian.

Therefore compared to rf systems, a laser transmitter produces bear widths several orders of magnitude narrower which is measured in terms microradians instead of degrees.

The basic calculations for beam power etc, however, may be easily carri out as per conventional rf communication system. Let the laser source pow P_t be distributed over the beamfront at the distance z. The optical pow collected over the collecting area A_r at the receiving side would be then

$$P_r = \frac{P_t A_r}{\phi_b^2 z^2} \qquad \text{...(14.13}$$

Eq. (14.13), may be rewritten in terms of antenna gain values and prop agation losses as being done in rf link analysis by using

$$g_t = \frac{4\pi}{\phi_b^2} \qquad \text{...(14.14}$$

and

$$L_p = (4\pi/\lambda z)^2 \qquad \text{...(14.15}$$

But since here the focussing parameters are also involved so the results given by Eqs. (14.14) and (14.15) for optical antennas would become mis- leading. Therefore these two equations are not used. Instead, Eq. (14.12) is substituted into Eq. (14.13) that gives

$$P_r = \frac{P_t (d_t d_r)^2}{\lambda^2 z^2} \qquad \text{...(14.16)}$$

where d_r is the diameter of the receiving optics. From Eq. (14.16) it is seen

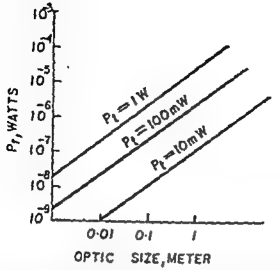


Fig. 14 4. Received Optical Power Versus Optical Size

It is evident that power levels comparable to those received in rf links are obtainable with only milliwatts of source po:ver and with optic (lens) diameters on the orders of a foot or less. This thus shows the significance of optical satellite communication. The received power P_r can also be converted to equivalent *photoelectron count rates* by the formula

$$n_r = \frac{P_r}{h f_o} \quad \ldots(14.17)$$

where h is the planck's constant and f_o is the optical frequency, n_r is represented in terms of photoelectrons per second. In actual practice the optical antenna system design is quite complex. The system combines the diode beams using a focal telescope with the cassegrainian structure. Mirrors also help in providing the perfect collimation.

14.4 Optical-Satellite Link Receiver

Analogous to its RF counterpart, the optical receiver consists of an antenna, filter, photodetector and then conventional receive electronic system. Receive antennas are also the telescopes whose main purpose is to focus the optical signal onto the photodetector and to reject as much as of the background radiation as is practical. The receive optical filters (also known as interference filters) are employed to eliminate background radiation that is not of the same wavelength as the optical signal. Infact the range of wavelengths around the laser wavelength allowed by the optical filter is called *optical bandwidth*. In

terms of wavelength this optical bandwidth $\Delta\lambda$ around wavelength λ_o is related to the optical bandwidth B_o in Hz around the frequency f_o corresponding to λ_o by

$$\frac{\Delta\lambda}{\lambda_o} \approx \frac{B_o}{f_o} \qquad ...(14.18)$$

Typical optical filter bandwidths at 1 micron generally range from 10-100 angstroms (1 angstrom= 10^{-4} microns) corresponding to an equivalent frequency bandwidth of about $B_o \approx 10^{11} - 10^{12}$ Hz (100-1000 GHz). It may be noted that sometimes field stop iris are also used whose purpose is to reject radiation that is not emitted from the region surrounding the transmitting telescope.

Optical detection systems are of two types namely the direct detection system and the hetrodyne system. Direct detection systems respond to the signal intensity and are the most widely used in optical communication systems. In the hetrodyne detection system the optical signal is combined with a local oscillator beam and then both the signals are focussed onto the same detector. Hetrodyne-detection systems are used primarily in the far-infrared region and they respond to signal amplitude. Figs. 14.5 and 14.6 indicate the basic principles involved with the direct detection and hetrodyne detection systems respectively.

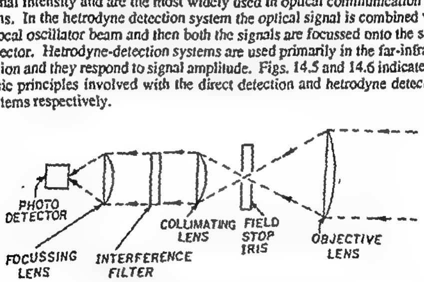


Fig. 14.5. Principle of Direct Detection Sy...

From Figs. (14.5) and (14.6) ... evident that in ... the photodetector converts quan... the ... it into photoelectron current flow. ... focus the ... the photodetector. Actually the ... the power of the fo... of ... onto the detector is equal ... lens so the photo... receiving field ...

over the detector area. Thus if the lens aperture area is A_r the Eq. (14.13) is still used for computing detector field power even though it does not explicitly involve the actual photodetecting area.

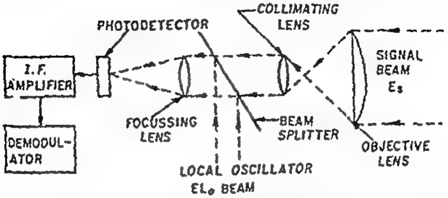


Fig. 14.6. Principle of Hetrodyne Detection

An optical receiver field of view is defined as the field arrival angles over which the lens will focus the impinging field onto the photodetector surface. This depends on the detector area A_d and the optical focal length f_c (note that $f_c = \sqrt{A_r}$). Thus the optical field of view is given as

$$\Omega_{fv} = \frac{A_d}{f_c^2} \approx \frac{A_d}{A_r} = \left(\frac{A_d}{\lambda^2}\right)\left(\frac{\lambda^2}{A_r}\right) \qquad \ldots(14.19)$$

In above Eq. (14.19) (λ^2 / A_r) is termed diffraction-limited field of view. Since detector area is on the order of millimeters or centimeters and is on the order of microns, so it is evident that optical field of view is many times larger than the diffraction limited field of view of the same aperture area.

Photodetector normally used in optical detection may be *P-I-n* diode or Avalanche photodiode (APD). These photodetectors are governed by their [illegible]

detection efficiency indicates the fraction of received power which is actually detected. It is wavelength dependent. It also depends on the material used in the photoemmissive surface. Its value lies in the range 0.15 – 0.90 for visible frequencies but falls off rapidly at the higher wavelength (lower frequencies). Thus the *detected* countrate of the optical receiver given by Eq. (14.17) may be written as

$$n_s = \left(\frac{\eta}{h_{f_0}}\right) P_r \qquad \ldots(14.20)$$

The gain of photodetector is increased by cascadeing the photoemmissive surface but this increases noise. This excess noise is represented in terms of excess noise factor defined as

$$F = \frac{1+\sigma_g^2}{(\overline{G})^2} \qquad ...(14.21)$$

where $\overline{G}$ is the mean gain and σ_g^2 is the gain variance. For an APD having gain of about 50-300, the excess noise factor is usually in the range of 2 to 5.

The responsivity of photodiode indicates as to how much current will be produced for a given power input. It is indicated by amps/watts. Mathematically it is expressed by

$$R = \frac{e\,\eta\,\overline{G}}{h f_o} \text{ amps/watt} \qquad ...(14.22)$$

where e is charge on electron ($e = 1.97 \times 10^{-19}$ coulombs).

The bandwidth of photodetector is different than the optical bandwidth defined by (14.18). The photodetector bandwidth actually determines the rate of power variation that can be detected. It indicates the highest frequency at which the power can be varied and have the variation detected by the output current. Typical bandwidth are usually 1-10 GHz.

It would be worthwhile to mention here that while using photodetector noise considerations are also to be taken into account. Here shot noise, dark current and thermal noise current of the post detection circuitry are taken into account. In addition some background noise power is also taken into account. All these together make the photodetector noise model as that shown in Fig. 14.7. In above figure $P_r(t)$ is the average laser power intensity modulated incident on the photodetector. P_b is the background radiation power. The noise processes as indicated in Fig. 14.7 may be expressed as

$$N_0 = N_{sn} + N_{dc} + N_t \text{ amp}^2/Hz \qquad ...(14.23)$$

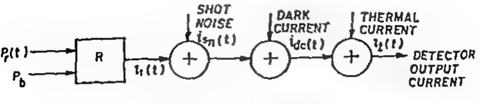


Fig 14.7. Photodetector Noise Model.

Here N_o represents the total receiver current process in terms of two sided spectral level. Similarly N_{sn}, N_{dc}, N_t are the two sided spectral levels for shot noise, dark current and thermal current respectively. These spectral levels are given as

$$N_{sn}(w) = \overline{G}^2 FeR\overline{P} \text{ amps}^2/Hz \qquad ...(14.24)$$

$$N_{dc}(w) = eI_{dc}\frac{\text{amps}^2}{Hz} \qquad ...(14.25)$$

$$N_t(w) = \frac{4KT^0_{eq}}{R_L} \text{ amps}^2/Hz \qquad ...(14.26)$$

Here $\overline{G}$, F and R are the detector gain, noise factor and responsivity, e is the electron charge, $\overline{p}$ is the time averaged mean received power, I_{dc} is the detector mean dark current (of the order of $10^{-16} - 10^{-12}$ amperes), K is the Boltzmann constant, R_L is the impedance loading the photodetector and T^0_{eq} is its equivalent noise temperature. Since the intensity modulation is used so if the information waveform s(t) is modulated onto the laser field then

$$P_r(t) = P_r[1 + \beta s(t)] \qquad ...(14.27)$$

where P_r is the average power given by Eq. (14.16) and β is the modulation index, $\beta \ll 1$. After detection (direct-detection) the output photodetected current would be given as

$$i(t) = R[P_r(t) + P_b] + i_{sn}(t) + i_{dc}(t) + i_t(t) \qquad ...(14.28)$$

where the first term in Eq. (14.28) is due to the impinging and background fields and the remaining terms are due to various noise sources as shown in Fig. 14.7. From Eqs. (14.27) and (14.28) it is evident that the first term of Eq. (14.28) can be expanded to give a constant term $[R(P_r + P_b)]$ plus a modulation term $[RP_r\beta s(t)]$. A filter for $s(t)$ with bandwidth B_m will produce a signal power

$$P_s = (RP_r\beta)^2 \qquad ...(14.29)$$

and a total noise power

$$P_n = N_o(2B_m) \qquad ...(14.30)$$

Therefore the photodetected SNR would be given as (direct detection)

$$SNR = \frac{P_s}{P_n} \qquad ...(14.31)$$

From Eqs. (14.29), (14.30) and Eqs. (14.23) to (14.26), Eq. (14.31) gives

$$SNR = \frac{(RP_r\beta)^2}{\left[eR\overline{G}^2F(P_r + P_b) + eI_{dc} + \frac{2KT^0_{eq}}{R_L}\right]2B_m} \qquad ...(14.32)$$

$$N_{sn}(w) = \overline{G}^2 FeR\overline{P} \text{ amps}^2/Hz \qquad ...(14.24)$$

$$N_{dc}(w) = eI_{dc} \frac{\text{amps}^2}{Hz} \qquad ...(14.25)$$

$$N_t(w) = \frac{4KT_{eq}^0}{R_L} \text{ amps}^2/Hz \qquad ...(14.26)$$

Here $\overline{G}$, F and R are the detector gain, noise factor and responsivity, e is the electron charge, $\overline{p}$ is the time averaged mean received power, I_{dc} is the detector mean dark current (of the order of $10^{-16} \sim 10^{-12}$ amperes), K is the Boltzmann constant, R_L is the impedance loading the photodetector and T_{eq}^0 is its equivalent noise temperature. Since the intensity modulation is used so if the information waveform s(t) is modulated onto the laser field then

$$P_r(t) \approx P_r\,[1 + \beta s(t)] \qquad ...(14.27)$$

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$$P_s = (RP_r\,\beta)^2 \qquad ...(14.29)$$

and a total noise power

$$P_n = N_e\,(2B_m) \qquad ...(14.30)$$

Therefore the photodetected SNR would be given as (direct detection)

$$SNR = \frac{P_s}{P_n} \qquad ...(14.31)$$

From Eqs. (14.29), (14.30) and Eqs. (14.23) to (14.26), Eq. (14.31) gives

$$SNR = \frac{(RP_r\,\beta)^2}{\left[eR\overline{G}^2 F\,(P_r + P_b) + eI_{dc} + \frac{2KT_{eq}^0}{R_L}\right] 2B_m} \qquad ...(14.32)$$

SNR given in Eq. (14.32) is also called *electronic* or *photodetection SNR* as opposed to the optical *SNR* at the input P_r/P_b. Eq. (14.32) may be rewritten as

$$SNR = \beta^2 \left[\frac{(n\,P_r / h\,f_o)^2}{\left[(n/hf_o)\,F\,(P_r + P_b) + \frac{I_{dc}}{\overline{G}_e^2} + \frac{2KT_{eq}^0}{\overline{G}^2 e^2 R_L} \right] . 2\,B_m} \right] \quad ...(14.33)$$

From Eq. (14.33) it is evident that the SNR is dependent on both P_r and P_b whereas both the dark current and thermal noise effects are reduced by the square or photodetector mean gain. Thus if high gain photomultipliers are used, it will aid in reducing the effect of post detection noise. In terms of count rate such as that described in Eq. (14.20), Eq. (14.33) may be written in the form as

$$SNR = \beta^2 \left[\frac{n_s^2}{\{F\,(n_s + n_b) + n_d + n_t\}\,.\,2\,B_m} \right] \quad ...(14.34)$$

where n_s is the detected current rate of optical receiver given in Eq. (14.20). n_b is the equivalent receiver background count rate given by

$$n_b = \left(\frac{n}{hf_o} \right) P_b \quad ...(14.35)$$

Similarly $$n_d = \frac{I_{dc}}{\overline{G}_e^2} \quad ...(14.36)$$

which may be considered as average number of dark current photoelectrons per second.

$$\frac{2K\,T_{eq}^0}{e^2 R_L} \quad ...(14.37)$$

which is the average numbe toel nd. Eq. (14.34) may also be rewritten as

$$\beta \quad ...(14.38)$$

Since *r* umber of signal cou *um* *limited* SNR

In hetrodyne detection system as shown in Fig. 14.6 a strong local field relative to received powers P_r and P_b) is added to the received field prior to hotodetection. Thus here the photodetector responds to the intensity of the ombined field (laser plus background plus local field). Here the local laser ower is much larger than the received power so the photodetected response urrent may be given as

$$i(t) = RP_L + 2Rf_s(t) f_L(t) A_r + 2RP_b(t) f_L(t) A_c \qquad \ldots(14.39)$$

Here P_L is the laser power over the detector area, $f_s(t)$ and $f_L(t)$ are the eceived loss and local laser fields respectively over the receiver area and $P_b(t)$ s the background power collected over the detector area common to both the ocal and focussed fields. It should be remebered that here A_r is the area corresponding to receive lens and A_c is the area on the photodetected. From Eq. (14.39) it is evident that in hetrodyne system the local laser power P_L plays quite an important role. It governs the average current and therefore the shot noise spectrum. The detection takes place for the product of incoming (modulated) laser field and the local laser field. This makes the modulation system for the laser satellite transmitter to use modulation techniques other than intensity modulation such as phase modulation, frequency modulation or amplitude modulation. Thus in hetrodyne system a difference frequency term (corresponding to the difference in frequency of transmitting laser and the ocal laser) is generated which is set to an RF frequency and further demodulation is carried out by conventional methods. It may be mentioned here that by focussing the local laser, the effective detector area can be reduced that will cause an equivalent reduction in the receiver field of view. Therefore the hetrodyne receivers receive less background noise as compared to that in direct detection receivers.

The post detection SNR in hetrodyne system may be calculated from Eq. (14.39). Assuming that the laser transmitter remains in the reduced field of view, the received power is

$$P_s = (2R)^2 P_L P_r \qquad \ldots(14.40)$$

where P_r is the received power over the area A_r. (A_r is the area of the receive lens). The detected noise is due to the mixed background, the shot noise and the detector output noises [$i_{dc}(t)$ and $i_t(t)$ in Fig. (14.7)]. Hence SNR post detection for hetrodyne system can be written as

$$SNR = \frac{4R^2 P_L P_r}{\left[eRP_L + \frac{4eRP_L N_b}{2} + eI_{dc} + \frac{2KT_{eq}}{R_L}\right] \cdot 2B_c} \qquad \ldots(14.41)$$

where B_c is the modulated carrier bandwidth at RF and

$$N_b = \eta N(f) \lambda^2 / hf.$$

Eq. (14.41) may be rewritten as

$$SNR = \frac{4\,(\eta / hf)\, P_r}{\left[1+2N_b+\frac{I_{dc}}{\eta P_L}+\frac{2KT_{eq}}{e\eta P_L R_L}\right] . 2B_c}$$

$$= \frac{4n_s / 2B_c}{1+2N_b+\left(\frac{n_d}{n_L}\right)+\frac{n_t}{n_L}} \qquad \ldots(14.43)$$

Here $n_L = (\eta P_L / hf)$ is the effective local laser count rate. It is evident from Eq. (14.42) that in hetrodyne system the laser power P_L acts like detector gain in reducing the effect of post detection noise. Hence high-gain photomultipliers are not needed in hetrodyne receivers. Further the background noise is also reduced and all these make the hetrodyne system quite attractive. But the overall design is quite complex. Because of these reasons such a system is not preferred in use with optical satellite cross-link. It should be noted that it is very essential that the polarization, amplitude distribution and phase of the local oscillator beam are matched to the signal beam.

14.5. Satellite Beam Acquisition, Tracking and Pointing

In optical satellite communication the transmitting beam should be quite narrow because it would then have maximum power spectrum. But this extreme narrowness in the beam creates beam pointing problems. It is infact very essential that the beam should be correctly pointed always to the receiving satellite otherwise the communication link will be disturbed. However it is allowed that the beam may be pointing within an pointing error $\pm \theta_e$ radians (normally θ_e is in microradians). This problem is not faced with the rf systems because there beamwidths are much wider. It is therefore clear that to determine pointing error, the transmitting satellite must illuminate the receiving satellite as accurately as possible. It then requires that the transmitting satellite should know the location of receiving satellite as accurately as possible. Also, it has to know its own altitude as accurately as possible so that it may aim its beam at the known direction correctly.

[illegible]

satellite firstly receives the beacon from the receiving satellite and then transmits its modulated laser beam (data etc) back to the receiving satellite. Thus the receiving satellite's location can be obtained and the pointing error be minimized. However, there might be a situation in which though the [illegible]

error). This situation would be as that shown in Fig. 14.8. In such a case it is

necessary to know the angle by which the receiving satellite has moved ahead (or back) of the transmitting satellite. This angle of drifting of the receiving satellite is called the 'point ahead angle'.

Thus if the tangential velocity of the receiving satellite is V_T meters/sec, then the point-ahead angle is given as

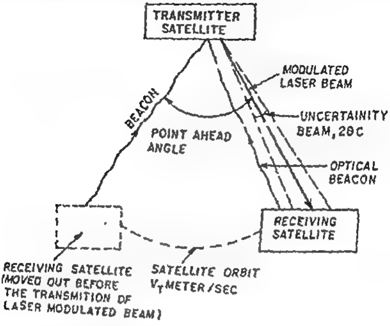


Fig 14 8 Point ahead Angle and Pointing Error Representation for Optical Satellite Cross Link

$$\alpha = \frac{V_T}{150} \text{ microradians} \qquad \ldots(14.44)$$

Incase the above point ahead angle exceeds the one half of the laser modulated beam's beamwidth then the use of this point ahead angle is being made. It is clear from Eq. (14.44) that the point-ahead angle is independent of the distance of optical satellite cross-link. For velocities at earth orbiting speeds ($V_T \cong 30$ Km/s), the point ahead angle is approximately equal to 200 microradians. Thus whereas the laser modulated beam's beamwidth may be of the order 10 to 100 μ rad, the point ahead angle is of the order of 200 μ rad.

In case the optical beacon is to be used both the transmitting as well as the receiving satellites would have optical transmitters and receiver and in such a situation the basic block diagram of the optical-satellite cross link would be as that shown in Fig. 14.9. Here the receiving optics tracks the arrival beam direction and adjusts the transmitting beam direction. Normally separate wavelengths are used for the optical beams in each direction. When there is no need of point-ahead angle the transmit and receive optics can be gimballed

together and the laser transmits through the receive optics. But when the point ahead is needed then command control (either stored or received from earth station) must adjust transmitting direction relative to receive direction. This requires an accurate satellite attitude control.

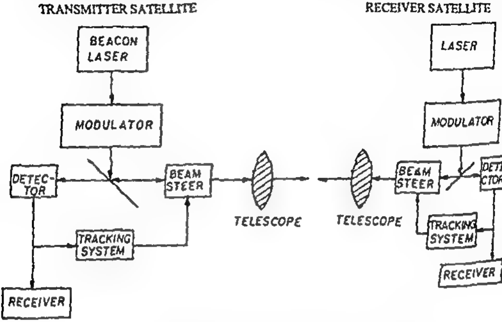


Fig 14.9 Basic Block Diagram of Optical-Satellite Cross link
(with the use of beacon)

With above discussions it is evident that before optical data transmissions, the transmitting antenna must acquire the beacon from the receiver. This beacon is transmitted from the receiving satellite with a beamwidth wide enough to cover the uncertainty angle of the beacon-receiving satellite. Once the beacon has been acquisitioned the satellite continuously tracks the LOS (line of sight vector) of the arriving beacon since the latter may vary due to the relative motion. In case the point ahead is needed, the satellite laser transmitter must point ahead by the proper angle and direction. In some cases [illegible] the RF [illegible]

After having LOS tracked and point-ahead angle determined the satellite optics points the return data beam to the proper position.

It would be of importance to mention here that though the above manouvers may be quite accurately carried out, even then some errors might be present there. These might be due to altitude reference errors in the satellite, mechanical and structural variations, boresight errors. However, the contributions of these errors are relatively quite small. But these errors can not be completely overcome as these errors are open loop errors. The contribution

due to vibration and boresight errors is generally below I microradians but the error due to altitude control may be high. It is therefore very essential to have proper altitude control so that overall pointing accuracy be as high as possible.

14.6. Deep Space Optical Communication Link

Fig. 14.10 shows a typical example of deep-space optical communication link of NASA. Here main space craft communication instrument is the optical transreceiver package called optranspac whose basic block diagram (isometric view) is shown in Fig. 14.11. The optranspac carries out various functions of the optical transmitter and revceiver as discussed in previous sections. For example it receives beceaon signal and performs beam acquisition, Tracking and pointing functions alongwith the uplink optical commands and ranging signals. It then returns coded data beam filled with telemetry data.

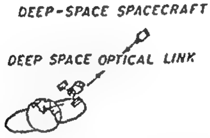
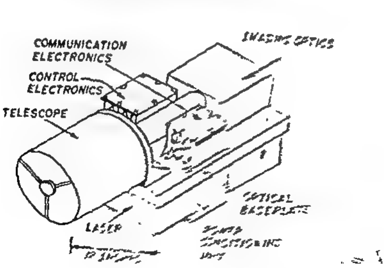


Fig. 14.10 Basic Overall Configuration of a typical deep Space Optical Communication link of NASA



In the NASA's transpac of Fig. 14.11 there is a telescope of 10-30 cm diameter used both for receiving and transmitting. A typical telescope of 27 cm diameter and 400 mW laser enables a 100 Kbps data stream to be recovered from Saturn with a 10-metre orbiting photon bucket (receive optics). The optranspac ordinarily weighs 50 kg and consumes 57 W of power. The imaging optics includes steering mirrors, beam splitters, alignment optics and detectors.

14.7 Review Questions

1. Explain the basic differences between the optical satellite communication link and RF satellite communication link. Mention their relative advantages and disadvantages.
2. Why is it not possible to have a direct optical communication link between earth station and communication satellite ? How does the atmospheric attenuation play its role ?
3. Explain the basic blocks of an optical transmitter and compare it with the analogous RF transmitter.
4. Explain and compare various laser sources being used in laser communication systems.
5. Explain optical satellite cross-link. How do different noises affect the working of the link? Derive the expression for resulting downlink signal after the uplink, cross-link and downlink transmissions have taken place
6. What types of modulation techniques may be used in optical satellite communication? Explain their working.
7. Explain the working of Direct and hetrodyne optical satellite receivers. Which one is preferred and why?
8. What kind of photodetectors are being used in optical communications? Explain their working principles
9. What are point error, point ahead angle, acquisition, tracking and pointing in optical satellite communications?
10. Explain various noises that can affect photodector's working? Find out the SNR formulas for the optical direct detection and hetrodyne detection cases

14.8. References

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FIFTEEN

Satellites and Cable Transmission Systems

15.1. Introduction

Cable TV transmission systems have been in operation since as early as 1949 even when there was no satellite communication system. With the availability of communication satellites and optical fibre cables new vistas in cable transmission systems have come up. Now a days cable systems are in the process of upgrading from 36 Channels to 60 Channels[1]. Thus the Cable transmission systems will help the viewers to receive signals not only from different parts of the country but also from different parts of the world. Teleports are advanced versions of cable transmission systems which are meant for TV signals, data and a variety of information transmission to the viewers. The modern concept of a Cable TV transmission network is as that shown in Fig. 15.1.[2] Hence along with the Satellite based TV signals, off air radio and TV signals, other kinds of information will also be available to the subscriber. The uniqueness of the system is the two-way capabilities of the cable system which will enable the subscriber to 'talk-back' to the programme provider.

15.2. Cable Channel Frequencies

Cable transmission systems are usually classified as MATV of CATV systems depending upon their configuration MATV, master aerial television generally refers to small distribution systems providing a service to blocks of flats and maisonettes, to office blocks and even to small housing estates. MATV systems initially used UHF but now a days these also employee VHF channels. CATV, community antenna television are fairly large systems which distribute television signals to large number of homes in towns and villages. Such systems usually contain special compensating equipment to ensure that the picture quality is not degraded as the signals travel along the length of the system which may cover many miles. In India CATV is also oftenly confused with the term *communal television* which is a television system that uses a master antenna to feed one or more centrally located television receivers that are set up in public places so that villagers can gather together to watch the programmes. CATVs employ VHF. It would be worthwhile to mention here

that sometimes the term SMATV (Satellite Master Antenna Television) is used to describe systems which have a satellite receiving antenna as well as the normal MATV receiving aerials.

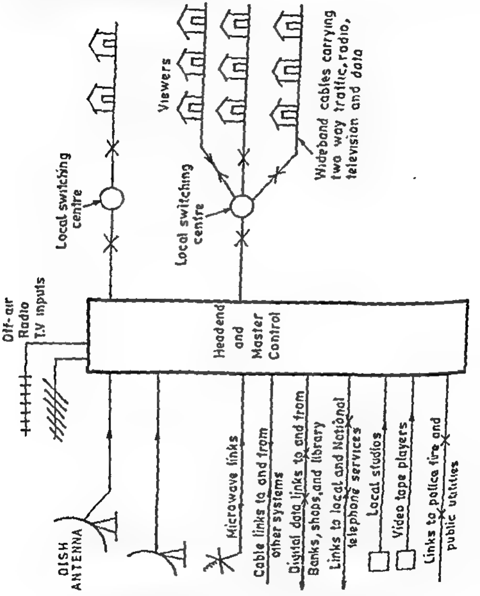

Fig. 15.1. Modern concept of a cable transmission network

Since the Cable transmission systems receive different frequencies from different sources so converters are used to change nonstandard channel frequencies to standard VHF channel so that ordinary TV receivers can demodulate the signals. Newer receivers are being manufactured with tuners

capable of turning more than one hundred channels. The cable channel frequency assignments generally used are given in Table 15.1.[5] Bidirectional cable systems normally employ a low band split (*i.e.* downstream channels above 50 MHz and upstream channels below 50 MHz) or a midband split with the division occurring at 150 MHz. As the upper limit of usnable cable-system frequencies increases, the frequency where the split occurs is also raised.

Table 15.1. Cable TV Channel Frequencies

Channel	*Frequency Range (MHz)*	*Carriers (MHz)*		
		Video	*Colour*	*Sound*
T-7	5.75-11.75	7	10.58	11.5
T-8	11.75-17.75	13	16.58	17.5
T-9	17.75-23.75	19	22.58	23.5
T-10	23.75-29.75	25	28.58	29.5
T-11	29.75-35.75	31	34.58	35.5
T-12	35.75-41.75	37	40.58	41.5
T-13	41.75-47.55	43	46.58	47.5
2	54-60	55 25	58.83	59.75
3	60-66	61.25	64.83	65.75
4	66-72	67.25	70.83	71.75
5	76-82	77.25	80 83	81.75
6	82-88	83.25	86.83	87.75
7	174-180	175.25	178.83	179.75
8	180-186	181.25	184.83	185.75
9	186-192	187.25	190.83	191.75
10	192-198	193.25	196.83	197.75
11	198-204	199.25	202.83	203.75
12	204-210	205.25	208.83	209.75
13	210-216	211.25	214.83	215.75
FM	88-108	—	—	—
14	120-126	121.25	124.83	125.75
15	126-132	127.25	130.83	131.75
16	132-138	133.25	136.83	137.75
17	138-144	139.25	142.83	143.75
18	144-150	145.25	148.83	149.75
19	150-156	151.25	154.83	155.75
20	156-162	157.25	160.83	161.75
21	162-168	163.25	166 83	167.75
22	168-174	169.25	172.83	173.75
23	216-222	217.25	220.83	221.75
24	222-228	223.25	226.83	227.75)
25	228-234	229.25	232.83	233.75
26	234-240	235.25	238.83	239.75

Contd..

Channel	Frequency Range (MHz)	Carriers (MHz)		
		Video	Colour	Sound
27	240-246	241.25	244.83	245.75
28	246-252	247.25	250.83	251.75
29	252-258	253.25	256.83	257.75
30	258-264	259.25	262.83	263.75
31	264-270	265.25	268.83	269.75
32	270-276	271.25	274 83	275.75
33	276-282	277.25	280.83	281.75
34	282-288	283.25	286.83	287.75
35	288-294	289.25	292.83	293.75
36	294-300	295.25	298.83	299.75
37	300-306	301.25	304.83	305.75
38	306-312	307.25	310.83	311.75
39	312-318	313.25	316.83	317.75
40	318-324	319.25	322.83	323.75)
41	324-330	325.25	328.83	329.75
42	330-336	331.25	334.83	335.75
43	336-342	337.25	340.83	341.75
44	342-348	343.25	346.83	347.75
45	348-354	349.25	352.83	353.75
46	354-360	355.25	358.83	359.75
47	360-366	361.25	364.83	365.75
48	366-372	367.25	370.83	371.75
49	372-378	373.25	376.83	377.75
50	378-384	379.25	382.83	383.75
51	384-390	385.25	388.83	389.75
52	390-396	391.25	394.83	395.75
53	396-402	397.25	400.83	401.75
54	72-78	73.25	76.83	77.75
55	78-84	79.25	82.83	83.75
56	84-90	85.25	88.83	89.75
57	90-96	91.25	94.83	95.75
58	96-102	97.25	100.83	101.75
59	102-108	103.25	106 83	107.75
60	108-114	109.25	112.83	113.75
61	114-120	115.25	118.83	119.75

5.3. Head-End Equipment

This consists of the antenna and amplifier to feed the signal into the main ine for the splitter (local switches) to the trunk lines. When there are several ntennas receiving signals for a cable transmission system then a balun is used vith each antenna to convert the impedance to 75Ω which is that of coaxial ine (cable). Output of these antennas is then fed into a 4 way hybrid (linear ixer). The output from the hybrid feeds into the distribution amplifier via a

than that indicated by a given curve. This is not applicable to intermodulation products or other discrete signals which are zero beat with visual carrier.

Carrier to-composite-Beat Ratio : The carrier to composite beat ratio in any television channel at any subscriber terminal shall be not less than 53 *dB*.

Echo Rating : The echo rating in any television channel at any subscriber terminal shall not exceed 7 percent.

Radiation : Radiation from a cable television system shall not be exceed the limits set out in Table 5.12.

Table 15.2. Radiation Limit

Frequency Range MHz	*Radiation Limit*	*Test Distance*
Upto 54	20	10
54-108	20	3
108-174	10	3
174-216	20	3
216-444	20	10

15.6. Network Architecture

In the earlier CATV systems tree and branch distribution architecture was used. Infact tree and branch architecture is most efficient in terms of cable and distribution equipment usage when signals have to be distributed in one direction, *from head-end to customer's home. It is why so many of this type* are already in use. In the case of pay-television (where individual TV Programmes are being changed) and two way interactive services, tree and branch system is not suitable. Infact for the satisfactory operation of two way interactive services it is essential that the customer requesting the service can be identified and charged accordingly and that the resulting information be sent to his house and not to any other. *For such systems, star network topology* is found to be suitable where the head end is being kept at the hub of star and each house is being fed by its own individual cable or cables. Such a star network system allows easily the cable network operator to send each household the programmes that it wanted and was prepared to pay for, and it would be easy to charge each customer the appropriate amount for each programme or service that was provided.

A better approach to serve a large community with two way interactive services is with the use of *switched star* network topology. The system concept is as that shown in Fig 15.2 and is in wide use in both the European as well as American cities. Here each switching centre is capable of serving 40 homes. Data cocentrators are substations and each concentrator feeds up to eight switching centres by means of a subtrunk cable. The central computer and equipment area *is equipped with two mini computers which provide and store*

the data needed to keep control the switching and routing of programmes and control information. These central computers control the two way flow of information passing through the data concentrators but the customer's equipment receives its commands from the concentrator *via* the switching centre.

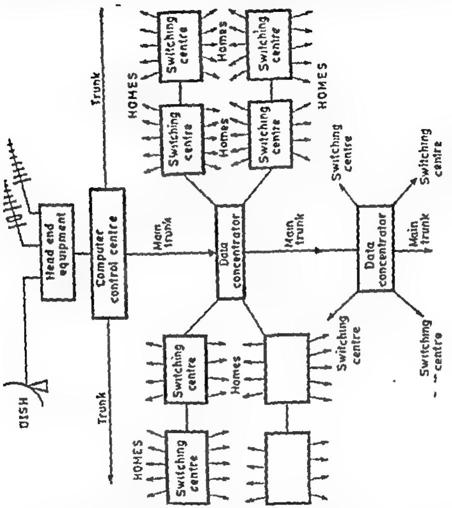

Fig. 15.2. Switched Star Topology in Cable TV System

The design of main truck feeder ... bound together ... th ... fr ... give a ... VHF/FM B and II rac ... be worthwhile to mention here that a variety of switched star type systems such as those of 'mini star' and 'multi-star' etc. have also been developed and are in use.

15.7. Optical Fibre CATV Systems

The inherent advantages of optical fibres over copper wire and also of optical fibre cables over coaxial cables prompt the use of fibre optics in Cable TV transmissition especially when large number of satellite TV signals are to be transmitted simultaneously to the subscribers.[6] However, fibre optic transmission systems are sophisticated ones involving optical transmitters/receivers which need expertise in high technology. Further the costs of laying out fibre optic cables, and associated equipment etc. are quite high as compared to that of established coaxial cable technology. Also the number of channels transmitted to the subscriber by Cable TV companies is still quite below which optical fibre cables can easily handle. All these increase the cost of subscriber at least 3 times which may not be tolerated by viewers at the moment. Thus, in future when the two way interactive services increase and cost of opto-electronic equipments decrease, Fibre Optic Cable TV may be widely acceptable. At the moment these are used in Teleport systems only.

Optical fibre cable TV networks are proposed to have some sort of star topology, rather than tree and branch. Infact optical fibre does not lend itself to the latter, because of the difficulty of splitting and tapping signals. Two variations of topology have been oftenly proposed, namely (*a*) the pure star in which every subscriber location is directly connected to a central switch by a fibre pair to provide two way services and (*b*) the hybrid star, in which subscribers are connected by their own fibre or wire pair to a nearby local switch where all the signals are available. Whether fibre optics are used in the local loop or not, it seems apparent that fibres carrying multiplexed signals will be used in the future Fibre Optic Cable TV Systems for the long runs from a central switch to local switches close to the subscriber. Sometimes optical fibres are proposed to be in the primary links and coaxial cable in the secondary links. Such hybrid cable TV systems are underway or beign planned in bigger way in North America, Europe and Japan. It is believed that costs for hybrid fibre systems are to be around $350 per service unit.

15.8. Indian Perspective

Satellite Cable TV Systems got momentum in India during gulf war when CNN of USA broadcasted live within India from the war zone. CNN (Cable News Network) offered free broadcasting rights to Doordarshan of CNN satellite broadcasts for a certain period. But free right to India automatically encouraged entrepreneurs to receive it directly from the CNN satellite broadcast through their own dish antennas. Since then Cable TV with the satellite dish antenna has been widely popularized in India. Several satellite antenna producing companies have come up. Shyam communications, which claims 10 million viewers and producing satellite antennas since 1978 see a better future for satellite communications. Other producers such as MC

Engineering, Cable vision by Su-Kam and Pioneer Electronics also in satellite antennas are gearing up hoping for a major demand in the near future. Su-Kam Cable TV Systems are working to take a slice of the growing Cable TV market. With the S band satellite dish antenna any satellite which has footprint on India whether it is Asiasat, Intelsat, CNN or any other can be easily accessed and can be connected to the viewers through cable TV networks.

The concept of cable TV, however, is not a very new phenomena in India too. The concept was first launched in India in 1978 in hotels[8]. Dish antenna installation began in 1983 and gathered momentum by 1989, shortly after colour TV sets got into middle class households. The growth of Cable TV newtworks has been reportedly quite fast. Big a rough estimate over 50 million Cable TV subscribes are in India and in Delhi only growth rate of Cable TV views is around 250 per day. Popular system models are CATV - 43%, MATV - 44%, Combination 13%. CATV Connotes satellite reception common dish antenna while MATV denotes feeding subscribers through common antenna. The distribution cost per connection is Rs 500-700 and the service charges are : deposits Rs 350-500 per channel and subscription Rs 100-175 per month. Usually the viewing time provided by the Cable TV operators is from 8 to 18 hours. While for star plus, BBC *etc.* sperate for 24 hours. The programme menu is: Residential - Line 50% Indian 42% (Doordarshan), Foreign 8%, Recorded - 50% Indian 32%, Foreign 18%.

With the rapid development of Cable TV in India and fast infiltration of foreign signals like those CNN, Asiasat (STAR TV), BBC, etc. Govt. of India appointed a Cable TV committee in June 1989 headed by M. Damodaran, joint secretary in the Ministry of Information and Broadcasting[9]. The committee comprised representatives from the Ministry of Information and Broadcasting, the Department of Electronics, the Department of space, the Communications [illegible]

be restricted for which it suggested controls. The main recommendations are : (*a*) CTV nets without a dish antenna may be permitted after devising a regulatory mechanism to cover their operation, (*b*) Only those programmes may be distributed which are declared fit for public consumption by the Central Board of Film certification. Programmes distributed by CTV nets should not offend national sensitivity or violate accepted values; (*c*) it should be compulsory for a CTV net to carry all signals which are available in that area and beamed by Doordarshan, (*d*) CTV nets should distribute recorded programmes unless exempted in special cases, (e) Fresh legislation is suggested to enable government to prescribe the necessary guidelines for regulating broadcasts, (*f*) A national cable authority should be established for regulating CTV nets and to ensure some uniformity regarding standards but licences should

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SIXTEEN

Echo-Cancellation

16.1. Introduction

In long distance telephone communication systems such as those through satellite link delayed echo is a great source of irritation and a variety of echo suppressors and cancellers, therefore, have been developed in practice. Fig 16.1 is an illustration of a typical long distance telephone circuit indicating the echo travel emanating from an impedance mismatch such as that from a hybrid coupler. These hybrid couplers are located at the two wire/four wire interfaces in the telephone circuit. These devices, made up of inductive elements in a balanced bridge configuration are passive four port directional couples as shown in Fig. 16.2

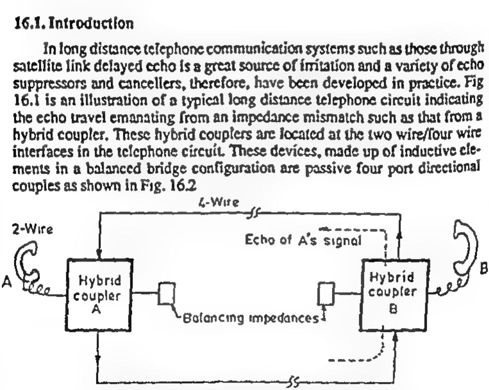

Fig. 16.1. Model for long distance telephone circuit. The four carrier section may possibly include a satellite link.

The ideal hybrid Coupler shall pass an incoming signal from "in" port to its "two-wire" port attenuating it by 3dB and does not pass any thing to the

... signals from

... the

... al-

... by the two wire

Considerable leakage and reflection signal may be generated by the hybrid

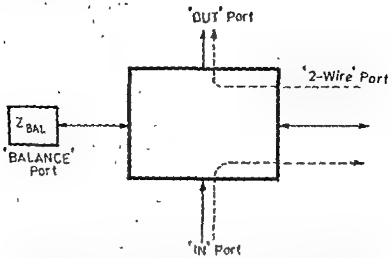

Fig. 16.2. Hybrid coupler as a four port directional coupler

computer. Thus, the echoes are generated at the hybrid and at all the other impedance mismatches in the telephone circuit including those at the telephone set or other terminating device. No echos will return from within the four wire part of the circuit since the channels are unidirectional. It can be seen from Fig. 16.1 that a long-delayed echo will result from speaker A's signal "leaking" through hybrid coupler B and returning to A's location. The echo also causes a serious trouble in digital data transmission.

16.2. Echo Control Techniques in Speech Transmission

Control of echo in the telephone network may be controlled by 3 techniques, namely the loss plans, echo suppression and echo cancellation.

Loss Plans. The technique is also known as VNL plans (Via net loss plan). Here a loss is introduced in the network in such a way that echo is lost. Infact the loss added to the trunk defends on its length. The expression governing the added loss is

$$DB = 4.0 + 0.4\,N + 0.102\,D$$

Where DB is the overall loss in decibels of the talker speech path, exclusive of the loss of the two subscriber loops at the two ends of the connection. N is the number of trunks in connection and D is the echo path round trip delay in milliseconds. The method is not suitable for very long distance trunks say over 1900 km where very long delays are involved.

Echo Suppressors. These are devices that introduce in connection a large loss in one direction or the other and the echo signal experiencing this large loss gets heavily attenuated. The principle of echo suppressor is as that shown in Fig 16.3. A large attenuation pad is inserted in one direction or the other. A speech detector is used to determine the direction of the active speech

controlling the direction to which pad is to be inserted. In Fig. 16.3, the echo suppressor passes speaker *A's* signal and blocks echo of speaker *A's* signal. A signal originating from speaker *B* will also be blocked. The echo suppressor when operating properly has been a quite satisfactory solution to the echo problem on circuits with moderate (perhaps less than 100 ms) round trip delay. On circuits with long (more than 200 ms) round trip delay *e.g.* satellite routed circuits, the distorting effects are much more pronounced. The performance of echo suppressor has been improved by restricting the satellite to so called *half hop mode*, in which one direction of the four wire connection was on the satellite and the other direction on a terrestrial circuit. (Thus limiting the round trip delay). It may be noted that two or more echo suppressors may not be used in tandem because the two suppressors may lock out during double talk which shall make the conversation impossible.

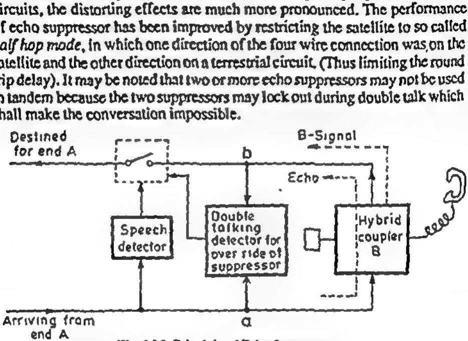

Fig. 16.3. Principle of Echo Suppressor

Echo Canceller : Satellite communication which has round trip delay of about 550 ms needs devices better than echo suppressors known as echo canceller. Thus the echo canceller is a sophisticated form of echo control which can effectively eliminate echo as an impairment even on very long delay channels and without regard to the double talk situation. The echo canceller involves a filter that is used in the place of echo suppressor and simulates the replica of echo signal. On subtraction of this echo replica with echo signal, the resultant echo signal gets zero. The schematic dragrain of an echo canceller using a filter is as that shown in Fig. 16.4. Here the filter simulates the echo [illegible] In order that the filter may work automatically. [illegible]

automatically without human intervention to produce the minimum residual uncancelled echo possible within its structural limitations. Echo cancellers built on above idea are too large and expensive for commercial service. It may

be noted that adaptive filter such as transversal filter, lattice filter and continuous time realization techniques have been used for echo cancellation.[2]

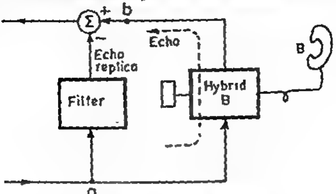

Fig. 16.4. Echo Canceller

16.3. CCITT Recommendations Regarding Echo Control

The CCITT recommends (CCITT recommendation G-131, yellow Book, Vol III-I, Seventh Plenary Assembly, Geneva, 1980) that overall loss of a connection may be adjusted so that echo signals are sufficiently attenuated or alternately, an echo suppressor may be fitted if the loss adjustment results in an excessive insertion loss[3]. Table 16.1 gives the CCITT Rec G131 net loss

Table 16.1. CCITT G131 Recommendations

Circuit Kilometer	*Length Status Miles*	*Net Loss dB*
0	0	0.5
250	155.3	0.5
500	310.7	0.5
750	466.0	1.0
1000	621.4	1.0
1250	776.7	1.5
1500	932.1	1.5
1750	1087.4	2.0
2000	1242.8	2 0
2250	1398.1	2.5
2500	1553.5	2.5

16.4. Echo Canceller for Digital/Data Communication

In digital networks the delays produced as a result of voice processing are significantly more problematic. The total end-path delay is comprised of three separate types: propagation delay over transmission lines, delays *via* the switching equipment and finally dispersion through channel banks and loaded VF Cable[4]. Typically a digital switch introduces upto 1.2 ms delay in one direction, together with between 1.8 and 6 ms for each transmux conversion and upto 0.5 ms plus dispersion *via* the PCM channel bank, and the transmission line causes even greater delays.

course the full two way delays are taken into consideration. The result of these delays building up obviously creates havoc with transmission intelligibility.

For digital/data communication systems to get rid of echo problem, digital echo cancellers are used. The first digital VLSI echo canceller chip was introduced in 1979. Its operation is illustrated in Fig. 16.5[5] The echo $y(k)$ is

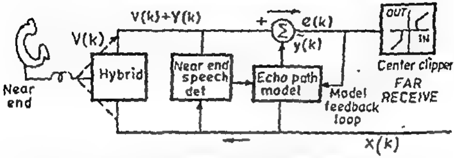

Fig. 16.5. Block diagram of digital echo canceller

formed by the discrete convolution of the far-end speech $x(k)$ and the echo path inpulse response $h(k)$. When $x(k)$ is present but the near end speech $v(k)$ is not, the estimated echo path impulse response $h(k)$ is adaptively undated and stored in an internal delay line of the VLSI chip, called the H-register. The adaptive estimation algorithm tries to reduce the absolute magnitude of the error signal $e(k)$, which is difference between $y(k)$ and $\bar{y}(k)$. When $e(k)$ is small, the echo canceller chip is said to have converged.

The near end speech detector of the VLSI echo canceller prevents the canceller chip from attempting to cancel the near end speech signal. Normally the canceller chip updates it echo estimate once per sample period. When near end speech is detected in the presence of far end speech (double talk) the speech detector inhibits further updating. The H register still retains its echo path estimate, however, and is thus able to continue to cancel echoes during double talk.

• The center chipper is an energy detector which in the presence of far end speech sets signals below a certain threshold to zero. The threshold can be either fixed at a low land or variable according to the level of the received far-end speech. If received speech is not present or if near end speech is present, the center clipper is bypassed. It has been tested that having the center clipper in the echo canceller chip indeed helps.

The echo canceler is needed at each end of the circuit. The near end canceller cancels echo for the far end speaker and vice-versa. Normally, the ... where one

echo canceller consists of the chip and its facility of interface circuitry. In the

analog environment A/D and D/A conversions are required to interface with the chip. In digital environment, PCM digital streams will have to be demultiplexed to per-channel level for echo cancellation and multiplexed back afterwards.

16.5. New Developments in Echo Cancellers Design

Echo cancellers are differentiated by their accuracy, intelligence and significantly by their speed of convergence. The advent of ASICs and more recently VLSI, has transformed both the size and performance of modern echo cancelled. Two concepts in particular have led to a major revolution in each cancellation technology, namely the integration and specialization. The ability to customise microchips, which was helped by digital signal processing principles went a long way towards overcoming the early problems of space efficiency and slow convergence tunes within echo cancellers. It is primarily due to the fact that DSP chip allowed for the integration of other functions in addition to echo cancellation.

New developments in ASICs technology, such as sub-micron gate lengths have also enabled further significant improvements in performance. The utilization of ASICs has enabled components to be custom designed, consolidating functionality and leading to fewer external devices being required one example of this integration can be seen in the tone disabler to identify modem/facsimile transmission. Usually an external component, the tone disabler can now be fully integrated within the core ASIC chip in state of the art echo cancellers.

As mentioned, the advent of VLSI brought with it the ability to condense functionality and scale down size, with the outcome that 12 echo cancellers, each supporting 24 channels (TI Standard), or 30/31 channels (CEPT standard), take up little more than the space of a looseleaf file. VLSI will undoubtedly continue to have a profound impact on component design in future. Experts believe that it will be possible to quadruple the number of echo cancellers which can be placed on one match box-sized microchip. The tally currently stands at a total of two cancellers per chip. ASICs have already advanced echo cancellation from generic microprocessing to customised processing for network and acoustic applications highlighting the move toward increased specialization.

16.6. Acoustic Echo and its Cancellation

Acoustic echo relates to reflected speech [illegible]

[illegible]

echo in a conference room includes reflected coupling between the speaker and microphone as well as direct coupling. Contributing factors include the size and acoustic treatment of a room, the quality and compatibility of audio

equipment, how much furniture is present and its construction and in the case of mobile use, the external noise factor. It is therefore quite essential to remove both multipath and direct coupled echo at source so that natural speech is experienced and howling is avoided. It must be remembered that acoustic echo has nothing to do with any impedance mismatching. As multipoint video conferencing becomes more common place, involving more than two different sites in the same meeting, the necessity for acoustic cancellation to be applied at each site is paramount in the system is to function successfully. It also puts additional emphasis on the performance of the acoustic echo canceller.

In the above multipoint videoconferencing context, the *echo return loss enhancement* (ERLE) becomes paramount because even a slight reflection in speech can create additive echo. Any or all of the multipath locations may cause, magnify and hear the echo and each connecting point contributes to the overall noise in the line. The aim, therefore is to isolate and eliminate echo at the individual sites so that the summed locations are not a cycle of interference.

Microphone gating techniques have been used in the past as one possibility to overcome acoustic echo. However their performance is limited as the acoustic echo suppressor because of half-duplex operation and clipped speech. The development of high performance acoustic echo cancellers has had a major impact in this field, providing the means to achieve completely natural speech. This has proved particularly important for video conferencing applications, where developments to improve picture quality have tended to leave audio a long way behind. With the use of echo cancellers video and audio performance are far more evenly matched.

16.7. Echo Cancellation Requirement in Other Communication Systems

Global mobile communication systems (GSM), digital cellular networks, personal communication networks (PCN), and VSATs all need echo cancellers. The requirement is for improved convergence times, ERLE and tail length flexibility especially with regard to GSM. Within the mobile cellular environment, compression techniques contribute significant delays as do transmission relays between the mobile vehicle, the cellular station and finally the telephone network. All of this necessitates longer tail length in echo cancellers in order to compensate. Convergence time is equally important for this application, with the mobile call undergoing inherently unstable network conditions. As a result the echo canceller must be able to converge readily on the changing telephone environment.

Echo cancellation is clearly a prerequisite for the rapidly growing digital network sector. The commercial realization of GSM in July 1991 has shown the need for echo cancellers whenever a call is made outside of the digital cellular network, as the call is patched through the analogue network. PCN,

though working on different frequencies is a sister system and needs echo canceller. Based on recent projections, regarding the expansion of the cellular market, one can confidently predict that this sector alone will support the main bulk of future echo canceller requirement. In the mobile telephone systems there is need for a miniaturized echo canceller which can be integrated within the mobile equipment. With the use of ASIC and VLSI technologies it is now becoming possible to achieve this. It has also now been possible to use such components for more than one function or in various applications.

VSATs and compressed voice systems also require the use of echo cancellation due to the creation of processing delays from the voice/data integration process for digital transmission and the continued interface with analogue circuitry. For example, the codecs installed in videoconferencing systems process and compress the picture for hundreds of milliseconds. Audio transmission, which is inherently faster, is deliberately delayed in order to achieve lip synchronization with video. It the teleconference occurs via a private satellite network, echo complexities are magnified, with tail length increasing.

16.8. Future of Echo Cancellers

It is believed that the arrival of ISDN and digital networking will ultimately remove both the cause and effect of echo. However it is still far. Less than 40% of the current global structures are digital and these has been a noticeable decrease in the ISDN conversion rate. This together with the longer life cycle for analogue within third word and soviet break countries indicates that a full conversion is unlikely for at least 30 years. The outcome of these predictions is that the echo cancellation is here to stay and within the next five years we are more likely to see new requirements emerging.

Algorithm development and integration will represent the most significant development thrusts. In the case of algorithm development, echo cancellation performance advances in line with the evolution of a proprietary algorithm. As new mathematical constants are researched tested and implemented, the formula becomes increasingly more accurate. Integration is another key development area, with echo cancellation in the future likely to be incorporated into PC compatible slip-in circuitry rather than external components.

It will be worthwhile to note that even the telephony requirement, predicted to decease with the introduction of ISDN, will not infact diminish until we have a fully door-to-door ISDN structure—a situation which may never materialise in the fullest sense. All the time the new digital networks still have to patch into the old analogue circuitry and so echo will continue to make its presence felt. It can therefore be concluded that echo cancellers shall stay through the 21 st century atleast.

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SEVENTEEN

Speech Coding Techniques

17.1. Introduction

Speech coding technology or digital speech technology is needed in all the present day digital voice communication systems say, it is microwave, satellite or fibre optic. Digital telephony needs telephone speech coding. These have application areas such as cellular radio systems, mobile communication (GSH), Personal Communication Networks (PCNs), ISDNs, PSTNs, and other modern digital communication systems. In the early speech coding systems, coding was used to be done at 64 kb/s PCM. The recent emphasis is on low bit rate speech coding mainly because of two reasons namely (*i*) to increase revenue and/or (*ii*) to provide a service which could not otherwise be provided.[1] Infact low bit rate codecs allow multiplexing several conversations onto a channel which would normally carry a single conversation (*e.g.* to replace one 64 k bit/s PCM channel with 8 speech channels carrying speech coded at 8 kbit/s).

Speech coding allows to compress the speech, store it and use it whenever needed. This has opened technology not only in communication but in man-machine interaction. Low bit rate coding allows speech storage at lower costs because then the amount of random access memory (RAM) or disc memory needed can be greatly reduced in voice mailbox or telephone answering machines. Low bit rate codecs utilize the radio spectrum efficiently. Personal cordless and mobile communication use the low bit rate codecs. Inmarsat is currently selecting a 9.6 kbit/s codec for use in a digital aeronautical telephone service. Their robustness to digital transmission errors in the services using digital radio links is added quality. High secure telephone communication systems such as digital encryption devices and modems also use low bit rate codecs. Codecs working on variable bit rates have also been designed that allow for the flexibility to mix speech and data services over the same connection.

17.2. Some Facts About Speech

The simplified electronic representation of human speech production system is shown in Fig. 17.1 (ref.2). According to this model, speech is generated by a sound source excitation that is either pulse like during voiced

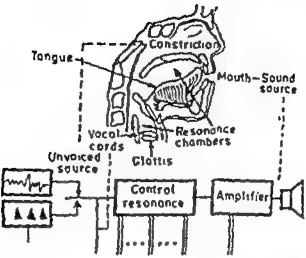


Fig. 17.1. Electronic model of speech productuction.

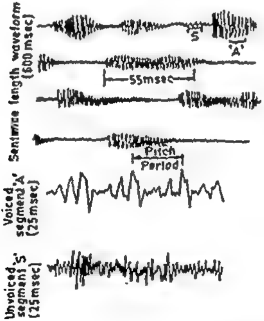


Fig. 17.2. Examples of "Longtime" and "short time" speech segments.

regions of speech, when the vocal cords are vibrating or noise like during unvoiced regions of speech because of turbulence at points of constriction in the vocal tract[3]. This excitation is then spectrally shaped by the vocal tract which acts as a time-varying acoustic filter. The speech waveform that is a result of this production process is shown in Fig. 17.2. When viewed over a "long" period of time (1/2 sec) speech is seen to be a highly nonstationary process due to the variation of amplitude, voiced/unvoiced/silence behaviour and the time varying vocal tract. However, over 'short' periods of time (20-40 ms), speech is locally stationary and has a well defined short-time spectrum.

The short time spectral models for the voiced and unvoiced segments of speech are given in Fig 17.3. The envelope of the spectrum is determined primarily by the frequency response of the vocal tract filter. The resonances of this filter are observed as the peaks in the spectral envelope and they are referred to as *formants*. Typically there are about four observable resonances in the speech spectrums from 0 to 4 kHz. During voiced segments, one observes in the time waveforms a pseudo-periodic structure. This is also reflected in

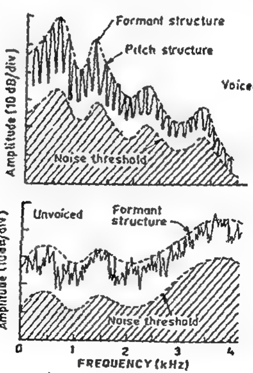


Fig. 17.3. Special models for voiced and unvoiced speech

the spectrum as a harmonic structure in frequency. During unvoiced regions, the five structure has a noise liked appearance both in time and frequency.

In the perception of human speech, the ear acts as like a Fourier spectrum analyzer or filler bank. Each channel of this and auditory filter bank appears to have its own automatic gain control and dynamic range limitations. Also, because of the construction of the ear, the presence of strong energy signals at low frequencies can interfere with and reduce the sensitivity of filter bands centered at high frequencies. This gives rise to the phenomenon called *auditory masking*, as illustrated by the shaded areas in Fig. 17.3. Essentially, any noise or distortion that is added to the signal is not perceived if it falls below this threshold.

Speech is a fascinating human attribute that can be analyzed, synthesised and recognised, it can also be compressed, stored and enhanced by digital signal processing techniques. The possible interactive speech systems and their strategic research areas are given in Fig. 17.4.

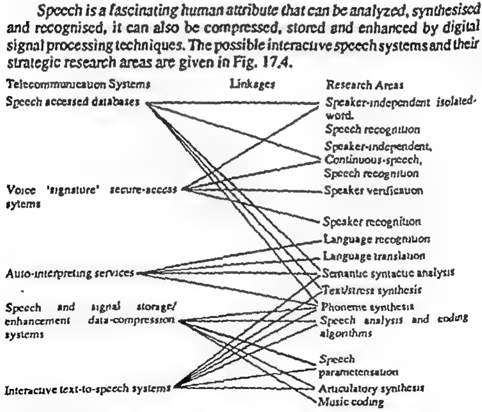


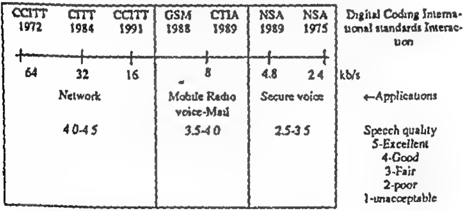
Fig. 17.4. Interactive speech systems and their stategic research areas.

17.3. Digital Speech Quality and International Digital Telephony Standards

The bandwidth of input speech may vary from about 3 kHz to nearly 20

opinion score (MOS) scale. A score of 4.0 on this scale is used to signify *high quality* or *near transparent coding*. The Term *network quality* implies high quality coding as a necessary but not sufficient condition. Sufficient requires further capabilities of the speech coder as demanded by the communication network environment. A score of 3.5 on the MOS scale denotes *communications quality*. This level of quality is characterized by a level of speech degradation that is easily detectable but not bad enough to impede natural telephone communications. The term 'Synthetic-quality' speech implies a signal characterized by high intelligibility.

A description of current state of telephone speech coding in terms of international standards activity, bit rate, typical application and decoded speech quality is given in Fig. 17.5. The bandwidth of speech is 3.2 kHz and the quality is measured on the MOS scale of 1 to 5. It may be noted that MOS values of 4.0 and 3.5 is regarded as minimum requirement for near-transparent quality and robust communications quality respectively. Present trends in speech coding include the achievement of near transparent or transparent quality of 8 kb/s, and the achievement of robust communications quality at 4.8 kb/s and lower.



CCITT - Consultative Committee for Telephone and Telegraph
GSM - Group Special Mobile
CTIA - Cellular Technology Industry Association
NSA - National Security Agency

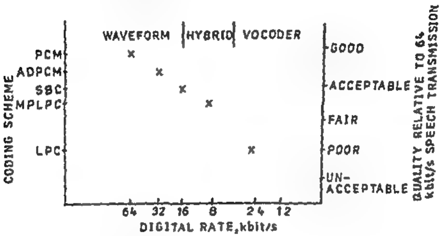
Fig 17.5. Digital Telephony International Standards

From Fig. 17.5 it is evident there are three major parameters in the design

considerations such as robustness to channel error and tandem behaviour are important in some applications, yet these remain secondary with respect to three basic requirements.[5]

17.4. Basic Speech Coding Methods

Basically all the existing speech coding methods may be grouped into three broad categories, namely (i) waveform coding where the speech signals are digitised directly from samples, (ii) parametric, where only certain parts of the signals are extracted and processed or hybrid using algorithms employing features of waveform and parametric coding techniques, (iii) vocoder (or source encoding). Fig. 17.6. indicates a quantitative description of these coding methods in terms of speech quality as a function of bit rate against the relative quality of 64 kbit/s PCM. Quality obtained by other than PCM such as ADPCM (adaptive differential pulse code modulation) SBC (Sub-band conding), MPLPC (multi pulse linear predictive coding) and LPC (linear predictive coding) are shown in Fig. 17.6.



PCM = pulse code modulation
ADPCM = adaptive differential pulse code modulation
SBC = sub-band coding
MPLPC = multi-pulse linear predictive coding
LPC = linear predictive coding

Fig. 17.6. Relative quality of speech coding methods.

[illegible]

that is not quite as good as that of wavefrom coders.

17.5. Low Bit Rate Speech Coding

Applications of low bit rate speech coding are already discussed in Section 17.1. The international CCITT standards for 64 kb/s PCM is G 711, for 32

kb/s ADPCM is G 721 and 16 kb/s CODER is G7 XY. In the range of 4 kb/s to 10 kb/s coding techniques are based on combined (hybrid) methods of wavefrom coding and vocoding. These are also known as parametric codes. They attempt to combine advantages of both methods to achieve an intermediate performance, that is a good "Communication quality" in this bit range. Coding algorithms include PCM, ADPCM, Linear Predictive Coding (LPC) (also referred to as Vocoding), Code Excited Linear Predictive Coding (CELP) and Low-Delay CELP (LD-CELP). The CELP algorithms typify the hybrid coders.

Table 17.1. DRT, DAM and MOS Scores for Stand Speech Coders

Coder	*DRT*	*DAM*	*MOS*
64 kb/s PCM	95	73	4.3
32 kb/s ADPCM	94	68	4.1
16 kb/s LD-CELP	94	70	4.0
8 kb/s CELP	93	68	3.7
4.8 kb/s CELP	93	67	3.0
2.4 kb/s LPC	90	54	2.5

Recent advances in hybrid coding have produced significant improvements relative to 2.4 kb/s vocoding and this is reflected in 4.8 kb/s algorithms with very high levels of intelligibility and acceptability as described by scores of Diagnostic Rhyme Test (DRT) and Diagnostic Acceptability Measure (DAM). However the subjective quality of 4-8 kb/s speech is significantly below the high quality score of 4.0 on the MOS scale. Table 17.1 summarized DRT, DAM and MOS performances of various speech coders in the range 64 to 2.4 kb/s. The DRT is a word-intelligibility measure while the DAM reflects acceptability for speech communication in a broader multi-dimensional sense.

It would be worthwhile to mention here that telephone systems such as cellular telephony based on a hybrid coding algorithm at 8 kb/s games the speech quality that falls below the high quality threshold (MOS = 4.0) but it provides a communication quality that is adequate to provide improvements over along FM telephony especially at low levels of radio channel quality (say, channel, signal-to-noise ratio or SNR below 15 to 18 db). The communication delay to the speech codec is expected to be on the order of 40 ms.

17.6 Audio Coding

The audio bandwidth required for various audio systems such as in telephone, AM radio, FM radio and compact is as per given in Fig. 17.7. It is apparent that as the audio bandwidth increases the perceived gain in terms of intelligibility, naturalness and speaker recognition also increases. Low frequency enhancement contributes to increased naturalness and presence, and high frequency enhancement provides greater intelligibility and fricative differentiation. Thus, the naturalness of wideband speech is a significant

feature for extended telecommunication processes such as audio conferencing

audio transmission quality. End to end digital connectivity in particular has made possible the inclusion of low frequencies, down to 50 Hz, in the transmitted audioband. The CCITT standard for 7 kHz audio(G.722) is a 64 kbit/s algorithm developed primarily for ISDN teleconfereucing and loud speaker telephony.

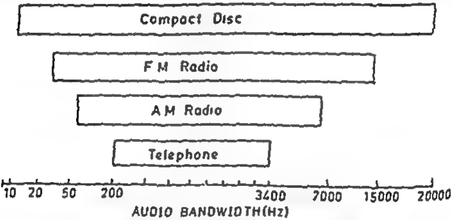


Fig. 17.7. Audio bandwidth requirement in different audio systems

Present trends are there for coding of wideband speech at 20 kHz audio. Several applications have been listed by International Standards Organizations for 20 kHz audio coding Table 17.2 lists these. HDTV is another major application of 20 kHz digital audio.

17.7. Hardware Technology in Speech Coding

Custom chips and devices, high speed microprocessors and programmable ICs, array processors and specialized hardware have already been developed for speech coding. In the area of Waveform Coding, Chips for complete μ law PCM A/D and D/A conversions (including anti aliasing

provision for program memory storage, data storage, address calculation, signal

data input and output, and a main airthmetic unit for multiplication, accumulation and numerical roundoff and logic operations. With this device algorithms such as AD PCM and subband coding have been realized using one DSP for an encoder, a second DSP for a decode and a μ law PCM coder chip for A/D conversion.

Table 17.2. Applications of 20 kHz digital Audio recommended by ISO

Applications	*Usage*
Electronic Publishing (End uses)	Integrated and interactive text, graphics, sound and video, [illegible]
Travel guidance	Preview of city news, flight and driving simulation, interactive video in public spaces, active guidance, surrogate travel.
Educational Applications	Electronics books Remote Classroom instruction
Business Applications	Electronic books, multimedia E-mail
Games	Stand alone games with audio and video from a storage medium, Multilocation games
Entertainment Applications	MTV audio on CD, TV program and movie storage and distribution, broadband stereo distribution, Previewing Systems
Data base Applications	Audio database applications, Audio & video either with onside or off side databases
Multimedia Memo and Bulletin Board	Bulletin board, computer conferencing with multi-media memos including audio, face to face teleconferencing
Broadcast Sound	Production, transmission of 'Contribution quality' audio transmission for distribution, digital audio broadcasting
Multimedia Art & Medical Applications	Education

For algorithms of high complexity such as adaptive predictive coding, adaptive transform coding and vocoder analyzers, this microprocessor approach is not sufficient. However, these algorithms have been realized in real time using array processing computers or special purpose hardware. As VLSI technology advances it is believed to have a chip of the above approach which will be infact single-chip DSP type processor.

It is worthwhile to note that there are three key tradeoffs that are of interest in the design of a speech codec, namely (*i*) overall quality, (*ii*) Cost or complexity and (*iii*) required bit rate Fig. 17.8 illustrates these tradeoffs for some of the hardware realizations of speech coding. The vertical scale corresponds to measure of speech quality based on 1 to 5 MOS scale. The horizontal scale

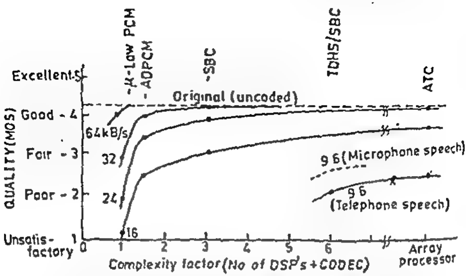


Fig. 17.8. Performance Versus bit rate and complexity for some speech codecs.

reflects a rough a measure of hardware complexity based on a total count of DSP chips plus the μ law codecs. The curves represent different bit rates, and points on the curves correspond to actual hardware realizations. It is evident *that as the coding at low bit rate is done the complexity factor* in the codec realization tremendously increases.

17.8. Speech Coder Performance

Speech Coder's performance in terms of speech quality measured on MOS scale of 1 to 5 is infact subjective one. For example MOS values are very difficult to duplicate in repetitions of an experiment and several factors may contribute to its variability. In digital communication systems, toll quality speech and broadcast-quality images cannot be always defined by means of an MOS requirement alone. An objective test for speech coder performance can be done by means of measuring its signal to noise ratio, SNR, Segmental Signal to noise ratio, SNRSEG, SNR MAX ; SNRMIN and Signal to uncorrelated Noise ratio, SNR_u.

In digital speech coding, the difference between coder input x (n) and coder output y (n) is defined as the reconstruction error r (n). The signal to noise ratio SNR is defined as the ratio σ_x^2/σ_r^2, the ratio of input signal variance to reconstruction error variance. Coder designs that maximize the SNR by minimizing σ_r^2 are called minimum mean square error (mm se) designs. The segmental SNR is defined as,

$$\text{SNSREG (dB)} = E\ [\text{SNR } (m) \text{ dB}]$$

where SNR (m) is that connectional SNR for segment m and the expectation is in practice a time average over all segments of interest in an input sequence. An appropriate segment length in speech work is in the order of 16 ms.

SNRMAX and SNRMIN give maximum and minimum values of SNR useful for the design of coders. SNRMAX indicates SNR values giving an enhanced quality of coding that is perceptually irrelevant typical SNRMAX value for speech and image signals may be in the order of 35 and 50 dB, respectively. Information about SNRMAX can prevent overdesigns of coders. SNRMIN values lie in the range of 0 to –20 dB. SNR_u is defined as signal to uncorrelated noise ratio given by

$$E\,[x^2(n)]/E\,[R_u^2(n)]$$

where $E\,[R_u^2(n)]$ is the residual uncorelated noise power that is due to mainly input dependent components present in the reconstruction error. An example of such problems occurs during slope onerload distortion in differential coding of speech and image signals SNR_u is found to be more meaningful than conventional total error variance.

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EIGHTEEN

Satellite Applications

18.1. Introduction to Satellite Applications

In the last seventeen chapters so far,we have studied different aspects of satellites and satellite communication at length. The topics covered so far include the basic principles of satellite communication, different types of satellites, satellite link design, satellite transmission and reception, satellite communication's vital components such as antennas, recent trends in satellite communication technology, evolution and present status of different aspects of satellite technology in India and so on and so forth.

One vital area that still remains to be explored at length, though it was touched upon here and there depending upon the needs of the topic under discussion, is the area of satellite applications. The satellite technology and its use is no longer the prerogative of the chosen few. Its horizon of applications has extended far beyond providing intercontinental communication services such as Radio, Telephone etc. It is a household name today. A satellite today is not being accessed by giant sized antennas located at the huge installations, the satellite signal today is also being tapped by roof top antennas. It not only provides long distance audio/video communications, It has started playing a significant role in the newer communication services such as Fax, Data communication, Cellular phones etc. Today, in addition to enabling you to talk to some one thousands of kilometers away within the comforts of your home in a matter of a few seconds, it also plays a pivotal role in the timely and accurate forecast of the weather. On one hand, satellites are being used as navigational aids by vehicles on land, in the air and on the sea, on the other hand, they are being used to unearth the hidden mineral resources which would otherwise have remained untapped particularly in countries having vast and not-so-friendly terrains. The list is endless.The application areas are multiplying and so are the quantum of applications in each one of these application areas. It is surely going to be the most widely used and the most important communication medium of the twenty first century. And it is be-

cause of this reason that all developed countries and the major developing countries including India have full fledged space programmes. Indigenous development of satellites for communication and remote sensing applications and also the development of satellite launch vehicles of different classes are the major activities of the Indian Space Research Organisation (ISRO). An international directory of different classes of satellites and satellite launch vehicles highlighting their salient features follow this chapter.

In the section to follow in the present chapter, we shall take a closer look at different applications that the satellite systems in general and satellite communication in particular offer to us. The emphasis is on the underlying principle, the potential and the contemporary status of these application areas.

18.2. Satellite Applications —Different Areas

Satellite applications can be broadly classified into the following categories namely

1. Satellite communication applications
2. Remote sensing and Earth observation application
3. Meteorological applications
4. Military applications
5. Scientific and Technological applications

In the field of satellite communication applications, Satellite television, Telephone and Data communication are the major application areas. In the category of Remote sensing/Earth observation applications, the typical ones are the discovery of hidden mineral resources, Terrain mapping etc. The meteorological applications include Weather forecasting, Flood forecast, Melting of glaciers etc. Military applications include providing strategic communication links between border forces and headquarters, spying, providing navigational aids to ships, aircrafts etc. In the category of satellites for science and technology, the applications include use of satellites for astronomical research, monitoring of different layers of atmosphere etc.

In the sections to follow, we shall discuss different applications belonging to each one of above the mentioned categories.

18.3. Satellite Television

Satellite television or satellite video communication belong to the same class of satellite applications. The two are one and the same. The two nomenclatures can be used interchangeably. Satellite television is infact one of the most widely used and talked about application areas of communication satellites as it involves masses at large . If the "satellite" has become a household name today, it is largely due to its television broadcast capability to bring live important events, sports or politically related, to our drawing rooms from places thousands of miles away. Who can ignore the small caption " Live via satellite" on the corner of TV screens when we are watching live telecast of a sports event.

Satellite television refers to the use of satellites for relaying TV programmes from a source point where these programmes originate to a large geographical area.There are various configurations used to implement what we call satellite TV depending upon the value of source end, role of satellite and the type of receive stations. But irrespective of the configuration used, the satellite basically receives a certain telecast that has been beamed up to the satellite by what is called the UP-LINK and then reflects the same without any change except carrier frequency translation towards earth for reception by all those who lie within its coverage area what we call as DOWN-LINK (remember uplink and downlink frequencies are different).

Direct Broadcast Satellite

One of the most common satellite TV configurations is based on simple point to multipoint connectivity feature of the satellite communication. It is diagramatically shown in Fig. 18.1 . It takes full advantage of the inside area coverage of the satellite's footprint. The TV broadcasting here is accomplished with one transmitting station and many receive only stations designated as TVRO stations. Fig 18.2 shows a typical set up showing use of direct broadcast satellite. The programme to be telecast is beamed up to the DBS via up-link from the studio. In the figure shown, the TV-studio has its own earth station. In case the earth station with the up-link capability is remotely located, the programme is usually sent to the earth station over a microwave terrestrial link .The down link is received at each TV station by its own Receive

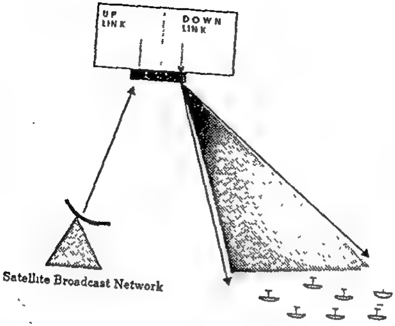


Fig.18 1

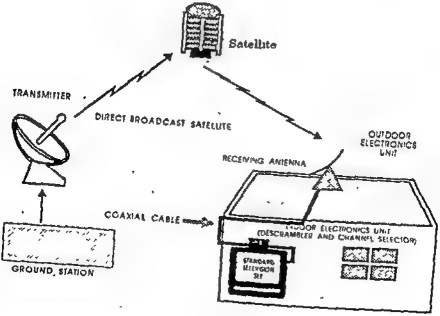


Fig. 18 2

only station, from there it is transmittted over the local TV channel stored on video tape.

A small variation of the configuration is in the live telecast of certain events such as sports events. The place of action in such cases is remote. In such cases, the signal picked up by the cameras is transmitted to the TV station with up-link facility as a microwave link if the distance involved is not more than few tens

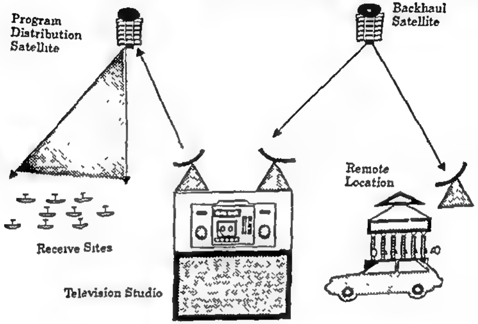


Fig. 18.3

of kms or a mobile earth station in the form of a van is posted at the site. The signal is then transmitted to the TV station over another satellite link on point to point connectivity basis (Fig 18.3).

A large number of countries have their own domestic satellite systems to be used for direct broadcast purposes. INSAT series of satellites though multipurpose in nature, also have direct broadcasting capability and are in a fact being used for the purpose Other popular DBS systems include AUSSAT (from Australia), TV-SAT (West Germany), TDF-1 (France), STC (USA) etc.

Cable TV (CATV)

The abbreviation CATV originally stood for Community Antenna Television which meant a common receiving antenna for the

community. The signal received by this common antenna was then distributed to large number of houses through network of coaxial cables. Such a concept is valid to huge buildings having hundreds of apartments thus eliminating the need for each house to have its own antenna dish on roof top. Fig 18.4 shows a typical set up. In the present day of cable TV, the cable TV operator has a root of receive only earth stations with a capability to receive telecast of one or even more than one satellites. He can achieve this by either having more than one receiving dish antennas or

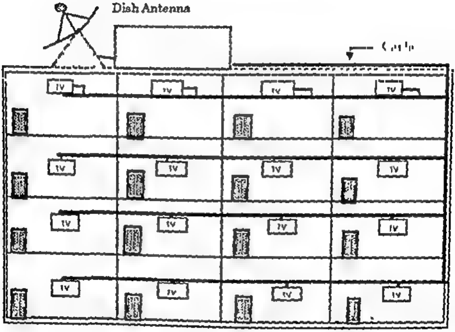


Fig. 18 4

even a single dish antenna with multiple feeds and each feed so aligned as to receive telecast from a different satellite. The received signal or signals are then simultaneously transmitted over a distribution network of coaxial cables on single point to multipoint connectivity basis to a large number of houses known as his subscribers who pay monthly fee for this service. The cable TV operator also transmit over the distribution network the

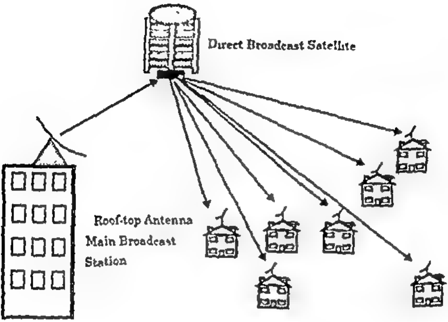


Fig 18.5

vodeo tape recorded programmes that they get from other sources in addition to showing programmes received from satellites

Direct Home Reception

Gradually, we are entering an era where each house top wil have its RO antenna capable of receiving TV programmes directly from satellites (Fig 18.5). Infact some of the companies have already started marketing TV sets with a built-in decoder. These TV sets in conjunction with appropriate dish antenna are capable of direct satellite TV reception.

18.4. Telephone Services via Satellite

. Satellites play a vital role in providing long distance trunk or point-to-point telephone services. Today infact about 80 per cent of international telephone traffic goes via satellite. Here too, the satellite like in any other telecom service serves the purpose of a repeater station .When compared to a terrestrial link, the satellite link is particularly advantageous when the distance involved

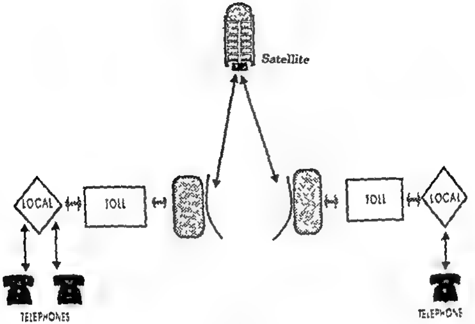


Fig 18.6

exceeds 1000 kms or when the region to be covered is sparsely populated or has difficult geographical terrain. Fig 18.6 shows a typical set up of international telephone service via satellite. Initially with communication via satellite suffered from echo problems leading to degradation in quality. With the development in device technology and digital techniques, this problem is overcome voice the introduction of echo cancellation measures.

18.5. Data Communication Services

Data communication services are the outcome of developments and advances made in the field of computers and telecommunications. The purpose of data communication is to link computers and other data processing facilities with other remotely located computers by a communication channel . The telecommunication channel could be terrestrial or satellite based. Terrestrial links for data communication have comparitively much lower data transfer speed, high cost, lesser reliability and throughput capability. Satellite links are attractive for data communication because of much higher data transfer rate capability, higher reliability and

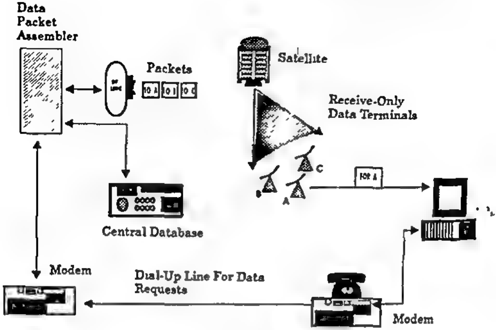


Fig. 18.7

much higher performance to cost ratio particularly achiev able with VSAT networks (Very Small Aperture Terminal).

Data Broadcasting Using Satellite.

Data processing based on simple point to multipoint connectivity configuration is the most commonly used data communication application implemented using a satellite. Fig. 18.7 shows the set up. Data from a central facility (a database for instance) is routed to the earth station with the uplinking capability via another set up called data packet assembler. The data packet assmbler is a digital processing device that receives the data to be broadcast, organises it into packets and places appropriate address bits at the beginning of each packet . Each data packet is thus self contained with source and destination addresses and therefore can be routed in any way over satellite and finally through a terrestrial packet switched network. Each data packet is even coded so that only authorised users can have an access to the information. Full access to all data is also provided in case of a news service. The data beamed up at the satellite is retransmitted towards earth to be received by "Receive Only " terminals. The receive only terminals have digital processing

capabilities to identify data packet addressed to them. The respective RO terminal receives the data meant for user terminals linked to them for subsequent delivery. As an illustration one of the user terminals at line A is a PC, The user terminals are usually linked to the central facility lines to enable them make request for broadcast of any additional data.

Interactive Data Communication

In an interactive data communication network, unlike data broadcasting, the remotely located user terminals are not only able to respond back to the central site, they can also exchange information between one another. Such a network is best implemented using VSATs, each VSAT supporting large number of user terminals. Fig 18.8 shows the typical arrangement in such an interactive network when the remote stations can transmit information to the central facility of the same satellite that does the the data broadcast and there is no need from terrestrial link.The data concentrator multiplexes the data flows from different user terminals and imports a single stream of bits to the VSAT indoor electronic unit. It also demultiplexes the data broadcast received from the satellite for delivery to prospective user terminals.

18.6. Satellites for Earth Observation

Use of satellites for a variety of earth observation applications has come of age beginning with use of TIROS weather satellite in early sixties, where TIROS sent map like outline of the world beneath the clouds, to the use of satellites for almost any coceivable application monitoring agriculture, forestry, detecting hidden mineral resources, forecasting weather and national calamities, oil exploration, cartography to mention some of the prominent ones. There has been a lot of work done on the development of satellites for earth observation not only in the developed world but also in the developing world. Some of the more popular and more recent satellite systems developed for this role internationally include LANDSAT, ERS-1, IRS etc. In the paragraphs to follow, we shall briefly discuss satellite based applications related to earth's observation.The applications being discussed include :

1. Cartography
2. Monitoring agriculture and forestry.
3. Oceanography

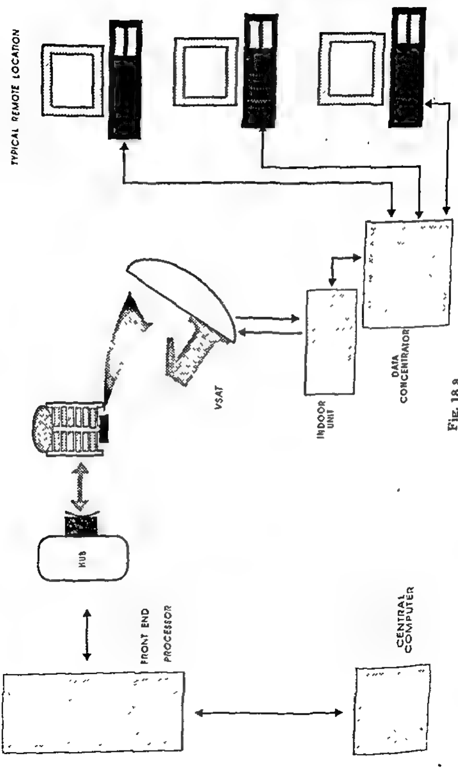

TYPICAL REMOTE LOCATION
VSAT
INDOOR UNIT
DATA CONCENTRATOR
HUB
FRONT END PROCESSOR
CENTRAL COMPUTER

Fig. 18.8

4. Ice Reconnaissance.
5. Monitoring oil pollution and air pollution .
6. Snow melt.
7. Mineral and oil exploration.

Cartography

One of the early applications for earth resources' imagery has been in cartography i.e. map-making. Satellites equipped with high resolution cameras have been used to correct and update certain features of existing maps in countries like USA , Russia. Satellite imagery has also been used to produce related maps for the construction of roads, railways and irrigation channels. It has

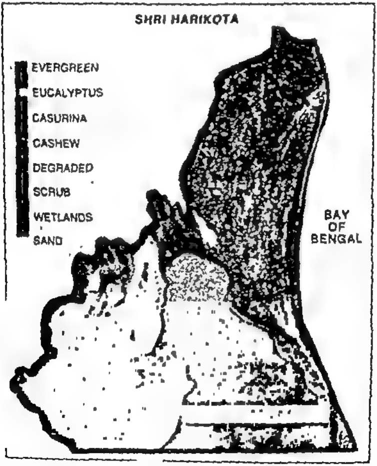


Fig. 18.9

also been used to map underwater features such as coral reefs which are potentially dangerous to shipping. Infact LANDSAT has played a very vital role in mapping more than 50 per cent of unmapped areas of Asia, Africa and Latin America at scales larger than 1:1,000,000. Space imagery is more cost effective as compared to other alternative methods due to the speed with which space surveys can be made. Fig. 18.9 shows a photograph taken from remote sensing satellite IRS-1A showing land cover map of Sriharikota.

Monitoring Agriculture and Forestry

Satellite imagery has been quite successfully used for better and optimum crop and forestry management. Remote sensing data from the earth observation satellite is used for several applications such as crop identification, agricultural crop acreage and field estimation , drought monitoring and assessment, flood mapping, land use and land cover mapping, wasteland management, forest resources survey and manangement and so on. Present day remote sensing satellites equipped with the state-of -the-art high resolution cameras are capable of monitoring characteristics like crop identification, crop yield, optimum plantation and harvest times, land fertility etc. over much smaller areas. For instance, cameras LISS-I and LISS-II on board Indian Remote Sensing Satellites IRS-1A and IRS-1B have spatial resolution of 72.5 m and 36.25 m respectively. The cameras planned for IRS-1C and 1D have still better spectral and spatial resolution and other features like stereo viewing, on board recording etc.

Backed by the capabilities of modern remote sensing satellites emerges a situation where we can have a global food watch that could help the mankind avoid disasterous food shortages . Many of the difficulties accompanying over or under production can be avoided by accurate forecast of optimum plantations and harvest timings, crop acreage etc. The optimum time to plant and harvest for a particular crop for maximum yeild can be found by checking soil condition and moisture content, by keeping an inventory of crops during the growing season and by giving advance warning of drought.

This type of agricultural watch could also allow an inventory to be made of tropical areas which could be potentially productive. It

could also give data on fertile and arid regions which could be made more productive by irrigation.

Satellite data has shown clear advantages in estimating the volume of timber across a large area of forests. When forests are being cut , it has been possible to monitor this and if necessary to recommend changes in the cutting pattern in the best interest of observation. Proper management of forest resources is particularly attractive for developing countries. Developing countries are increasingly aware of the need to manage their forest resources not only to meet their timber requirements but also to preserve the ecological balance and to prevent erosion, silting of dams and pollution of coastal waters. In India, the IRS-series satellites have become the mainstay of National Natural Resources Management system with the department of space as the nodal agency. The remote sensing data from IRS satellites is used for several applications such as agricultural crop acreage and yield estimation, flood mapping , drought monitoring and assessment, forest resources survey and management, water resources management and so on .

In Brazil, LANDSAT imagery has been used to monitor a programme for controlled development of the Amazon forest for various purposes including cattle grazing. From satellite imagery, it has also been possible to make rapid assessment of places where forest fires have burnt the ground.

Fig 18.10 shows IRS-1B imagery showing Bombay-Manmad pipeline corridor Fig.

Fig 18.11 shows preliminary flood risk zone Kosi river interpreted from satellite images.

In India, satellite data was used to provide technical guidance and training to Gujrat forest department for making forest working plan. Soil moisture mapping capabilities were established by making use of data from ERS-1 satellite. Coral reef mapping on 1:50,000 scale was completed for the Gulf of Kachch, Lakshadeep,Gulf of Mannar and Andeman and Nicobar islands. Fishery prospect charts were generated for Gujrat estate using data from IRS series satellites. Data from IRS-1A was used in 1991 to study the environment impact of river valley project at

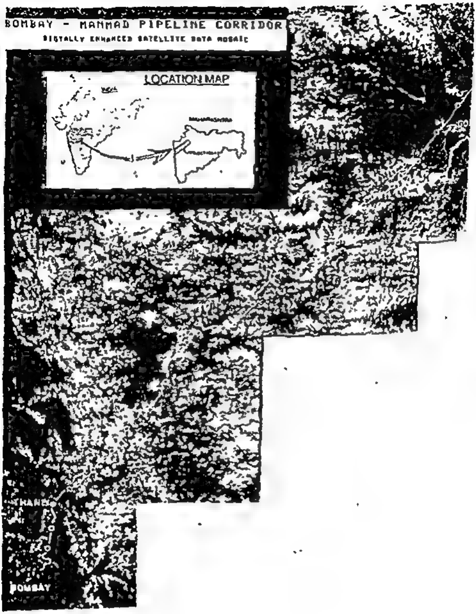

BOMBAY - MANMAD PIPELINE CORRIDOR
DIGITALLY ENHANCED SATELLITE DATA MOSAIC
LOCATION MAP
NASIK
BOMBAY

Fig 18.10

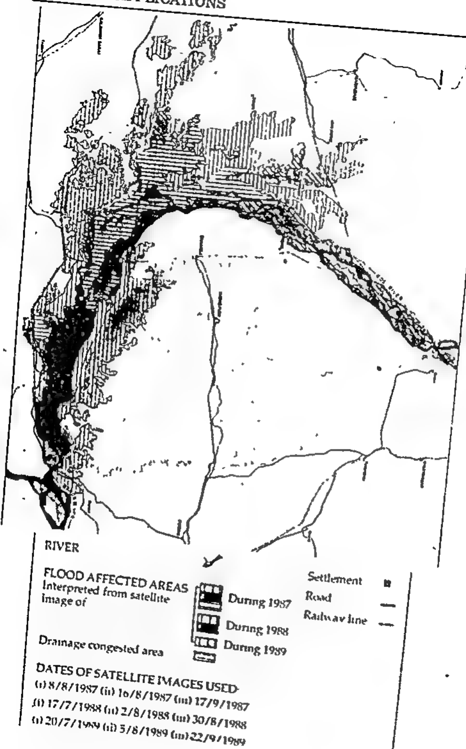

RIVER
FLOOD AFFECTED AREAS
Interpreted from satellite image of
During 1987
During 1988
During 1989
Drainage congested area
Settlement
Road
Railway line
DATES OF SATELLITE IMAGES USED
(i) 8/8/1987 (ii) 16/8/1987 (iii) 17/9/1987
(i) 17/7/1988 (ii) 2/8/1988 (iii) 30/8/1988
(i) 20/7/1989 (ii) 5/8/1989 (iii) 22/9/1989

Fig. 18.11

Tehri. Satellite data is also been used to study the environmental impact of Sardar Sarovar project.

Oceanography

Satellite data can be used to determine sea conditions such as Sea surface temperature, Wind speed, Wind direction, Local air temperature and Moisture content etc. Satellites have also been used to make pictures of ocean waves, ice fields, ice bergs, ice leads and sea conditions along the coastal lines.

Fishermen can make use of satellite derived information of thermal boundries in the ocean to get the additional catch advantage . Sa-tellites are also being used by the countries, Russia for instance, to study oceans for measuring the sea surface electromagnetic radiation in the visible , infrared and microwave bands. Research of this kind is leading to observation systems in which different satellites collect different types of data from land and sea surfaces to allow better use to be made of the earth's resources.

In India too, a national remote sensing programme for ocean related application, sponsored and funded by the Department of Ocean Development is under progress. Sea Surface Temperature (SST) charts are being generated from satellite data analysis. Based on the SST data and thermal patterns, the potential fishing zones are being identified and maps are being disseminated to about 80 fishing land centres of the country. The feedback indicates that fish catch has increased significantly in these areas.

More and more different types of sensors getting placed on board the present day earth observation satellites, they are likely to get data on subjects such as (i) Coastal sedimentation and pollution (ii) Conservation and use of fish stocks (iii) Ship routing making use of ocean currents (iv) Wave forces for use in the design of off-shore structures and wave power generating systems (v) Mapping of polar ice caps, Ocean temperatures and winds for improved climate and weather forecasting. Fig. 18 12 shows sedimentation dispersal patterns as revealed by satellite data off Sunderbans coast.

Ice Reconnaissance

Remote sensing satellite data can be used to advantage in forecasting behaviour of ice and ice bergs which is very crucial to

Fig. 18.12

navigation of ships in cold waters. Navigation of ships in these cold waters depends upon the knowledge of the properties, distribution, variability and behaviour of ice bergs. Forecasts require knowledge of air and sea temperatures, precipitation, wind and currents. Data on ice thickness can be obtained by infrared sensors abroad satellites under cloud free conditions. Passive and microwave radiometry has shown promise for all weather conditions while high resolution photography monitors the coast and in -shore areas.

Monitoring Oil Pollution, Air Pollution

Satellites can be very effectively used for monitoring oil slicks in the sea. It is very difficult to see such leakage from aircrafts which in any case, are restricted in vision to narrow bands of ocean because of their low altitudes. On the contrary, the oil slicks can be spotted very effectively by satellites on global scale except in the places of persistent low clouds.

To do so, the space borne sensors measure the amount of sunlight reflected from the sea surface. Spilled oil stands out clearly from the ordinary sea water in the near ultraviolet region around 0.38 micron and in the near red around 0.6 micron. Polarisation measurements on the reflected light from the oil spills also shows sharp contrast. It is not only possible to detect just the oil spillage, light and heavy oils can also be distinguished. Light oils appear brighter. The volume of oil leakage can also be assessed by repeated observations. Knowledge of the type, quality and volume of oil is important in tracing their source of leakage.

Remote sensing satellites equipped with instuments like correlation interferometer are being used for mapping of those parts of atmosphere which have high, low and average concentration of carbon monoxide. By repeitive scanning over long periods it is possible to identify the so called REMOVAL SINKS. Unless the removal machanism can be defined, it is very difficult to predict the futuristic behavioural pattern of carbon monoxide content in the atmosphere.

This study attains still more significance as there is also a growing concern that the amount of carbon dioxide in the atmosphere is increasing worldwide - because 20th century man continues to burn so much fossil fuel .This will have the effect of

putting on increasingly thick blanket over the earth which allows sunlight to reach the earth's surface as before but would reduce the escape of its heat by reflection back into space, thus trapping ever more heat near the surface. Use of remote sensing satellites for atmospheric studies is discussed again under the heading of Satellites for Scientific Applications.

Snow Melts

Routine photography of snow covered ground and mountains and monitoring of snow cover characterstics such as cover area, thickness, density etc. to make predictions of snow melt can be effectively, speedily and economically performed by satellites. Accurate predictions of snowmelt are important for optimum water management for power generation, irrigation, controlling flood water etc. In India, snow melt run -off predictions based on the satellite data have been made available to Bhakra-Beas Management Board.

Oil And Mineral Exploration

Satellite data can be used for oil and mineral exploration. The data can be used by geologists to see earth's interlocking features including large folds and ruptures which give clues to mineral deposits. Transcurrent faults as indicated by satellite data can be used to make searches from unknown deposits of oil. Minerals can be identified by rock colour and topographic form. Not only this, information about faults and fracture zones derived from LANDSAT imagery has been used in the past in selecting sites for nuclear power stations and routes for pipelines.

In India too, data from remote sensing satellites IRS has been effectively used for identifying favourable locates for gold mineralisation in the Schist belt near Garwal town in Mehboobnagar district of Andhra Pradesh. Structural continuity of the Gadwal schist belt with that of the well known Kolar Schist belt was inferred from the IRS data.

18.7. Satellites For Weather Forecast

Satellite data is being used for forecasting weather for more than three decades now. The first weather satellite,TIROS-1, was launched by U.S.A. in 1960 and was used by a large number of countries to monitor the behaviour of atmosphere over a large area of the earth. The present day weather satellites equipped

with highly sophisticated instrumentation provide information on cloud formation, cloud type and position, extent and intensity of frontal depression, thunderstorms, hurricanes, sea breeze circulation, typhoons and so on and so forth. Sequence of pictures covering the same area can be effectively used to determine the movement and development of different features. Details of snow cover, sea ice, sea surface temperatures, cloud top temperatures and wind at different heights in the atmosphere are also extracted regularly from satellite pictures. Measurements of temperature and humidity throughout the depth of the atmosphere are also sometimes carried out by weather satellites.

The accuracy of a weather forecast depends largely on the quantity and quality of observational data from the surface of the earth and surrounding atmosphere. The speed with which the data is made available to data computing and analysis facilities plays a major role. Satellites are particularly valuable for providing data where conventional observations are sparse or non-existent. Their ability to transmit data quickly to operational users is a very important asset.

There are two categories of operational weather satellite systems. The first operates in a polar orbit and the other operates in a geostationery orbit. The geostationary orbiting satellite can monitor weather determining atmosphere parameters over a very large area almost continuously whereas a polar orbiting satellite can provide complete global coverage every twelve hours.

The most important piece of equipment abroad a weather satellite is a RADIOMETER. The radiometer measures the amount of radiation. Measuring in the visible part of spectrum provides pictures about prominent features such as clouds, deserts etc. Infrared measurements provide information both during the day as well as during the night. Infrared pictures show the relative temperature of the different features. Pictures are usually obtained in black and white. Black areas indicate usually high temperatures while white areas indicate low temperatures. As a result high clouds appear in various shades of grey. Some weather satellite pictures are shown in (Figs 18.13 to 18,16.).

In India too, the multipurpose INSAT-series satellites have been providing meteorological data for years now. The Meteorological Data Utilization Cenre (MDUC) of Indian

Fig. 18.13

Fig. 18.14

Fig. 18.15

Fig 18.16

Meteorological Department (IMD) processes and disseminates the INSAT meteorological images. Upper winds, Sea surface temperature and Precpitation index data are regularly generated by MDUC/IMD. The 0600 hours GMT VHRR image derived wind data are regularly put on the global telecommunication system (GTS) of the World Meteorological Organisation (WMO). The 0300 hours GMT full disk IR pictures are being transmitted as radio fascimile broadcast everyday for reception in the neighbouring countries. The INSAT VHRR (Very High Resolution Radiometer) data is now available in real time With the commissioning of direct satellite retransmission service of processed VHRR data over a CXS link, it is now possible to provide SDUC (Secondary Data Utilisation Centre) type of data at any location in the country, irrespective of its distance from MDUC/IMD and availability of point-to-point terrestrial transmission circuits.

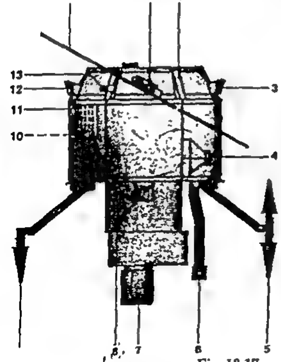
The main weather satellite systems include the polar TIROS-N/NOAA series from U.S.A, the geostationary orbiting GOES-Series (Geostationary Operational Environment Satellite) built by Hughs for Japan, Indian INSAT and Europe's METEOSAT-series

18.8. Satellites For Scientific Studies

Satellites orbiting the planet earth at relatively lower altitudes (typically several hundreds of kilometers) have been and are being used to carry out a variety of scientific experimental studies including studying the characteristics of upper region of atmosphere, probing other planets and stars and so on. The significance of using satellites with significant payloads to carry out experiments of scientific and research nature arises from the fact that for many years, scientists were denied the insitu investigation of the upper reaches of the atmosphere except by observation from the earth and the instruments lifted by aeroplanes and sounding ballons. Earth observation had its own limitations. Only a few windows were open in the atmosphere for recording of data, generally those in the optical wavelengths. Also the atmosphere at low levels accessible to soil observations has become so polluted as to deny any useful observations. Satellites equipped with scientific payloads offer a very good and effective solution to carry out atmospheric and space studies

One of the earlier studies was particularly designed to investigate aerosol concentration in the stratosphere. The experiment was known as Stratospheric Aerosol and Gas Experiment (abbreviated SAGE). The payload was launched in the satellite applications Explorer mission-B. The SAGE photometer looked at the sun through the stratosphere's gas and aerosols every time the satellite entered or left the earth's shadow. The instrument saw fifteen sun rises and an equal nomber of sunsets during each twenty four hour day. From repetitive observations, the concentrations of ozone and aerosols could be determined. Fig 18.17 shows the sketch of SAGE satellite. Studying space is another important mission of scientific satellites. Space studies include probing different planets, studying inter-planatory forces, solar wind and solar flare phenomenon etc. Fig. 18.18 shows a huge eruption on sun photographed by Skylab-3 and Fig 18.19 shows solar flare prepared from data received from SMM.

In India too, Indian Space Research Organisation (ISRO) is pursuing the programme of using space borne vehicles for carrying out scientific experiments. Work on the development of Rohini



1. Solar array deployment mechanism.
2. Yo-Yo despin support (4)
3. Sun sensor No 3
4. Scan wheel A
5. S-band telemetry antennas B
6. Magnetometer
7. SAGE instrument
8. Sun sensor No 4 near side No 5. far side
9. S-band data antenna A
10. Louvre panel (under)
11. Thermal control radiator
12. Sun sensor No 2
13. Electrical umbilical connector
14. Deployable solar arrays

Fig 18 17

series satellites stand testimany to that. The 106 kg SROSS-C satellite successfully launched on board the ASLV-D3 into a near

Fig. 18.18

earth orbit of 433 km apogee and 267 km perigee carried the scientific payloads namely (i) the Gamma ray burst experiment and (ii) Retarding potential analyser. Both the payloads functioned well and provided a lot of useful data for scientists till the satellite re-entered the atmosphere.

SROSS-C2 launched subsequently in May, 1994 from another ASLV flight has also started providing data. The Retarding Potential Analysiser (RPA), one of the two payloads on board SROSS C-2 has started collecting data on thermal structure and electron densities of the ionosphere. SROSS-C3 is also planned for launch in 1995-1996.

IRAS (Infrared Astronomical Satellite) has been anothe revolutionary satellite launched in 1983. It was the first satellit to carry an all-sky survey to look for astronomical objects emittin infrared radiation. It was an international venture involving th U.S., the U.K. and Netherlands. Fig 18.20 shows the IRAS imag of a recently discovered new born star (arrowed) embedded in a

Fig. 18.19

cloud of dust and gas. The young protostar called B5-IRS1 is about 100,000 years old only. Another astronomical satellite of European origin was EXOSAT designed to measure position, structural aspects and spectral and temporal characteristics of X-ray sources. This satellite made detailed studies of known and new X-ray sources in our and other galaxies. It made more than 2000 observations mainly on the physics of Neutron stars and

Black holes. EXOSAT also discovered quasi-periodic oscillations in the star GX5-1.

Hubble Telescope, Infrared Space Observatory (ISO), Granat, Gamma Rays Observatory(GRO), Advanced X-ray Astrophysics Facility(AXAF), Hipparcos, Extreme Ultraviolet Explorer (EUV) and Soho-Cluster missions are some of the newer craft for scientific studies.

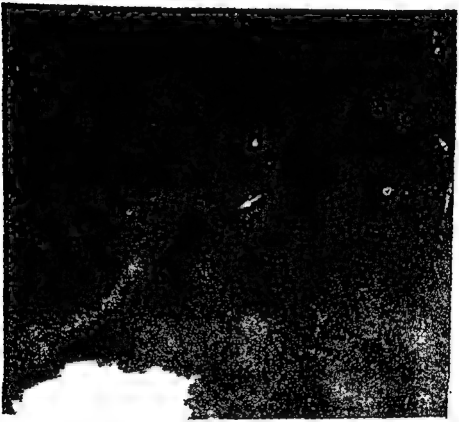


Fig 18 20

Hubble telescope will allow observations of stars as faint as the 27th magnitude. In the ESA's Soho-cluster project , Soho will observe the sun, its corona and the solar wind while the four cluster craft will study the reactions of the magnetosphere to varying

solar conditions (Fig 18.21). Hipparcos was an astronomical satellite intended to make accurate measurements of the parallaxes, proper motion and position of 115000 selected stars in our galaxy .It was launched in 1989 but it failed to attain geostationary orbit.

18.9. Satellites For Military Applications

Right from the beginning, satellites have had important military roles to play both during war time as well as peace time but in recent years, dependence on them has increased dramatically. The earlier methods of reconnaissance, communication, navigation, remote sensing etc. have always had some constraints or the other due to being land based or needing the services of specialised aircrafts or ships. The extent to which satellite technology has superseded these earlier methods of communication, remote sensing, reconnaissance etc. is largely responsible for ever increasing role of military satellites. Some of the more commonly heard military satellite applications include:

1. Reconnaissance and Intelligence gathering functions
2. Command and Communications
3. Navigation satellites
4. Early warning satellites
5. Meteorological functions
6. Nuclear detection

Reconnaissance and Intelligence gathering functions

The most widely known types of military satellites are those used to verify the extent and composition of military forces. One of the most important role of reconnaissance and intelligence gathering satellites is the verification of the agreed limitations of strategic arms and the monitoring of new military developments. This is achieved by a variety of electronic and photographic means.

One of the earlier satellite-series launched by U.S.A in early sixties was the Discoverer. The data from Discoverer, basically a photo reconnsaissance satellite was instrumental in ending US fears of a massive earstwhile Soviet ICBM build-up. Infact, Discoverer-29 was credited with photographing the ICBM base at Plesetsk. The Discoverer-series phot-reconnaissance satellites had re-entry capsule which could be used to carry the exposed

1. Re-entry capsule

2. Equipment bay including computer inertial reterence package. poropellant pressurisation and horizon scanner

3. Fuel (UDMH)

4. Oxidant (IRFNA)

5 Destruct charage

6 Nitrogen and helium bottles

7. Bell 8096 rocket engine
Agena B Length 25ft (7.6m)

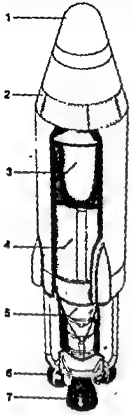
Laboratory) project. Fig 18.23 shows the labelled sketch of Manned Orbital Laboratory.

Another space borne reconnaissance technique that has emerged in the late eighties is the use of radar. The radar signals from a reconnaissance satellite penetrate the cloud cover. The reflected echoes can be processed to produce images that resemble photographs. Photography using radar has the advantage that it is not hampered by bad weather's darkness.

The other surveillance and reconnaissance related military applications of satellites include (i) the electromagnetic reconnaissance (or ferret) dealing in the location and cataloging of military radio and radar stations and (ii) ocean surveillance.

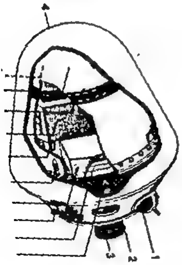
Command and Communication

The reconnaissance and intelligence gathering functions though very important represent however a very small fraction of the true scope and diversity of the capabilities of the military satellites. Command and Communications is one such application The satellites today meant for the purpose can provide instant communication between the operational forces and their national command authorities irrespective of the distance or time of the day. The idea of military communication satellites took shape with launching of Courier 1B in 1960 to be followed by the DSCS-series (Defence Satellite Communication System) Satellites beginning in 1966. DSCS-1, DSCS-2 and DSCS-3 series launching continuing till the mid eighties. The other popular military communications satellites (both past and present) include SEASAT for naval applications, SDS (Satellite Data System) used to communicate with US nuclear forces in polar regions, LES-series (Lincoln Experimental Satellite) for tactical communication and TACSAT used to link, by means of small transmitters, aircrafts, ships, land vehicles, FLEETSATCOM to provide global military coverage for USAF and Navy (Fig 18.24), MILSTAR intended to be successor to FLEETSATCOM to provide strategic and tactical communications for USAF, Army and Navy, NATO-III series to provide rapid and secure communications among NATO members and SKYNET-IV (Britain's military communications satellite to replace SKYNET-II) to provide links among ships, mobile terminals on land and control centres



1. Re-entry capsule
2. Equipment bay including computer inertial reterence package. poropellant pressurisation and horizon scanner
3. Fuel (UDMH)
4. Oxidant (IRFNA)
5 Destruct charage
6 Nitrogen and helium bottles
7. Bell 8096 rocket engine

Agena B Length 25ft (7 6m)



1. Coid gas storage tank
2. Thrust cone
3. Retro-rocket
4. Explosive bolt
6. Recovery parachute and chaff
6 Stabilization jets.
7. Parachute cover.
8. Expiosive pistons
9. Flashing light
10. Instrumentation package
11. Dye markers
12. Recovery capsule
13. Radio beacon (inside).
14. Ablating re-entry sheld.

Fig. 18.22

Navigation Satellites

The navigational satellites are currently capable of providing data to enable position fixing with an accuracy of a few meters. NAVSTAR is one such satellite to provide navigation. NAVSTAR is designed to aid weapon aiming to enable users fix their position with much higher accuracy than was possible with other navigation systems. NAVSTAR provides a position accuracy of 15m. NAVSTAR is a replacement for the US Navy's TRANSIT-series. TRANSIT-series is a series of navigation satellites operated by the US Navy but also used by civilians, especially sailors. Receivers fix position through a combination of Doppler effect and accurate orbital details transmitted by satellites. Positional accuracy of about 100 m is possible in most parts of the world.

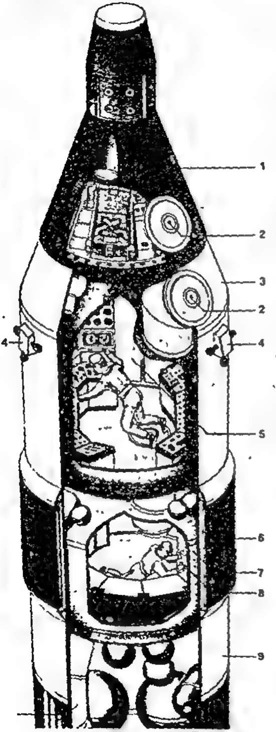
Early Warning Satellites

Early warning satellite development was basically aimed at providing an advance warning to the owners of a missile attack. The initial experiment in this direction began under the USAF's MIDAS (Missile Defence Alarm System) programme with the idea that the infrared sensor on board the satellite would detect the exhaust of a rising ICBM. The results of the MIDAS experiment were not very encouraging due to sunlight reflected from clouds and the operational system was abandoned.

The Integrated Missile Early Warning Satellite (IMEWS) first launched in 1970 has means of discriminating between real missiles and spurious effects. These satellites carry large infrared telescopes and television cameras to transmit photos of detected ICBMs to prevent false alarms that plagued MIDAS. IMEWS series satellites are capable of detecting ICBMs within seconds of ignition. This programme was renamed as Defence Support Programme(DSP).By mid 1980's, a network of four satellites, one over Russia, two over Pacific and Atlantic, and the fourth over South America had been established.

Meteorological Functions

Use of satellite data for accurate weather forecast has been one of the earlier benefits of the space programme. The weather satellites not only provide long range forecast for military planners, they also play a key role in reconnaissance satellites. They provide advance information to the mission planners of reconnaissance



1. Gemini B spacecraft
2. Hatches for external inflatable tunnel (one of four different crewtransfer methods considered)
3. Gemini adapter
4. Attitude control jets
5. Pressurised lab with control consoles air purification and circulation systems toilet (commode) and hygiene area main control consoles food storage and preparation bio-med sleeping couches spare spacesuit and other emergency equipment
6. Solar panels (stowed)
7. Pressurised lab with control and telemetry consoles attitude control TV extra emergency gear spare spacesuit food and water second commode etc.
8. Console for pointing and tracking telescope
9. Test module for experiments and/or equipment
10. Aft tunnel

Fig. 18.23

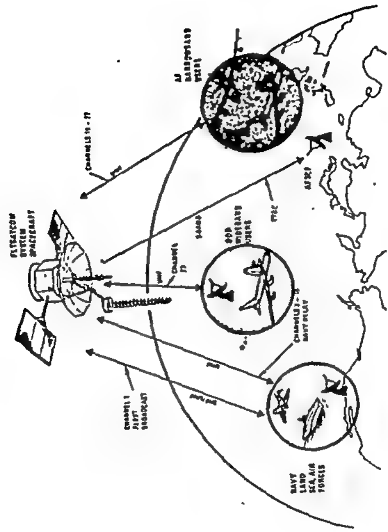


Fig. 18.24

satellites on whether the target area will be clear of cloud cover or not when the reconnaissance satellite makes its pan. This eliminates wastage of limited reconnaissance film. DMSP/BLOCK-5D (DMSP stands for Defence Meteorological Satellite Programme) series satellites provide weather information to both military and civilian users. Data is made available to the civilian users through NOAA (National Oceanographic and Atmospheric Administration). The payload includes line scanning radiometer operating in visual and infrared and precipitating electron spectrometer. These satellites provide infrared and visual imagery, temperature moisture soundings, auroral detection and upper atmosphere soundings.

Nuclear Detection

The idea of nuclear detection using satellites perhaps originated in U.S.A. while finding ways to police a nuclear test ban treaty. The solution came in the form of Vela Satellite which had the capability of detecting a nuclear explosion at the distance of Venus or Mars and report its yield and other characteristics. Twelve satellites of Vela-series (Vela-1 and Vela-2) were launched during time period 1963-1970. Thereafter, IMEWS early warning satellite had taken over.

NINTEEN

Satellites and Satellite Launch Vehicles

Introduction

This directory gives a brief description of all the major satellite systems and satellite launch vehicles. Amongst satellites, the directory includes the satellites currently in service as well as new ventures with a firm go ahead. Some of the old systems which are no longer in service have also been included for the sake of continuity. The satellites discussed here have been broadly categorised as:

1. Communications satellites including direct broadcast satellites 2. Satellites for earth observation 3. Satellites for scientific and technological experiments 4. Military satellites and 5 Weather satellites.

The satellite launch vehicles have been grouped according to their manufacturers. The companies and organisations covered include :

1. Aerospatiale (France) 2. American Rocket Company (AMROC), U.S.A. 3. Arianespace (France) 4. ASI (Italy) 5. British Aerospace Space Systems (U.K.) 6. Cape York (Australia) 7. CIS (Russia) 8. CNES (France) 9. CNIE (Argentina) EER /SSI (U S.A) 10. E Prime (U.S.A.) 11. European Space Agency (France) 12. General Dynamics (U.S.A.) 13. Great Wall Industry (China) 14. General Technology Systems (U.K.) 15. ISRO (India) 16. ISAS (Japan) 17. IAE (Brazil) 18 Iraq (Iraq) 19. Israel Space Agency (Israel) 20. LTV (U.S.A.) 21. Martin Marietta (U.S.A.) 22. Mcdonnell Douglas (U.S.A.) 23. NASA (U.S.A.) 24. NASDA (Japan) 25. National Launch System (U.S.A.) 26. Orbital Sciences (U.S.A.) 27. Pacific American Launch Services (U.S.A.) and 28. Strategic Defence Initiative Office (U.S.A.).

[illegible] technical features and brief descriptions of different [illegible] ilar in- [illegible] able-6.

Abbreviations used to describe propellants and orbits in Table-6 :

A50 : Aerozine 50, **GEO** : Geostationary Orbit, **GTO** : Geostationary Transfer Orbit, **HTPB** : Hydroxyl Terminated Polybutadiene, **Kero** : Kerosine, **LEO** : Low Earth Orbit, **LOX** : Liquid Oxygen, **MMH** : Mono Methyl Hydrazine, N_2O_4 : Nitrogen Tetroxide, NMO_3 : Nitric Acid, **PATP** : Polybutadiene Acrylic Acid Acrylonitrile Terpolymer, **RP-1** : Kerosene derivative, **Sun Sync** : Sun Synchronous Orbit, **UDMH** : Unsymmetrical demethyl hydrazine, **UH 25** : Unsymmetrical hydrazine.

Table 19.1. Communication Satellites

Satellite	No.	Mfr.	Bus	Stabilis-ation	Payload	Design Life,yrs	Location	Launch	Brief Description
ANIK (Fig 19.1)	C3	Hughes	HS-376	Spin	16 Ku-band	10	115°W	Nov 82, STS	ANIK-Series satellites provide TV, voice, Data and video traffic. New ANIK-E series satellites combine both C and Ku-band capacity. These have replaced ANIK-C and ANIK-D series satellites
	C2	Hughes	HS-376	Spin	16 Ku-band	10	110°W	Jun 83, STS	
	C1	Hughes	HS-376	Spin	16 Ku-band	10	107°E	April 85, STS	
	D1	Spar aerospace	HS-376	Spin	24 C-band	8	104°W	Aug 82, Delta	
	D2	Spar Aerospace	HS-376	Spin	24 C-band	8	110°W	Nov 84, STS	
	E1	Spar Aerospace	GE Astro spacebus 5000	3-Axis	24 C-band 16 Ku-band	12	107°W	Dec 90, Ariane	
	E2	Spar Aerospace	GE Astro spacebus 5000	3-Axis	25 C-band 16 Ku-band	12	111°W	1991 Ariane	
ASIASAT	1	Hughes	HS-276	spin	-	-	105-116°E	Apr, 90	ASIASAT-1 is the former Westar-6 satellite which was retrieved by space shuttle in 1984. The coverage

Fig. 19.1

Fig. 19.2

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilis-ation	Payload	Design Life yrs	Location	-Launch	Brief Description
									areas include China, Pakistan, Thailand, Philipines
AURORA	1	GE Astro	Satcom 3000	3-Axis	24 C-band	10	$143^{o}W$	Oct 82, Delta	AURORA Satellites provide telex, data, telegram, radio and television services
	2	GE Astro	Satcom 3000	3-Axis	24 C-band	10	$138^{o}W$	May 91, Delta	
ASTRA (Fig. 19.2)	1	GE Astro	Satcom 4000	3-Axis	16 Ku-band	10	$19^{o}W$	Dec 88, Ariane	Born from the abandoned LUXSAT project in 1983, the Direct Broadcasting satellite ASTRA is the product of Societe Europeene des satellites (SES) with primarily Luxembourg investment.
	2	Original Satcom-K3	Satcom 4000	3-Axis	16-Ku band	10	$19^{o}W$	Nov 90, Ariane	
AUSSAT	1A	Hughes	HS-376	Spin	15 Ku-band	8	$160^{o}E$	Aug 85, STS	AUSSAT series satellites provide TV, Radio, Telephony, Telex, Fax,Data Mobile, Educational Video, Electrnic funds transfer and other services to Australia and papua New Guinea, Australia's AUSSAT has proved to be one of the greatest successes in domestic
(Fig. 19.3)	1B	Hughes	HS-376	Spin	15 Ku-band	8	$164^{o}E$	Nov 85, STS	

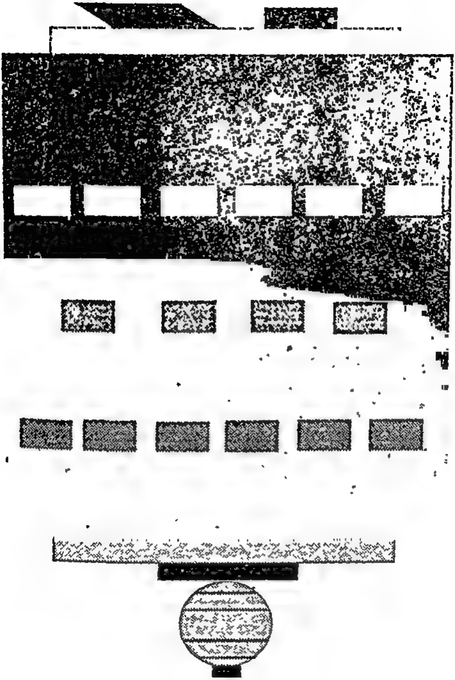


Fig 19.3

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilisation*	*Payload*	*Design Life, yrs*	*Location*	*Launch*	*Brief Description*
	1C	Hughes	HS-376	Spin	15 Ku-band	8	164°E	Sep 87, Ariane	cmmunication satellite business.
	2A	Hughes	HS-601	3-Axis	15 Ku-band, 1 L-band 1 Ka-band	15	156°E	1991, Long March	
	2B	Hughes	HS-601	3-Axis	15Ku-band 1 l-band 1Ka-band	15	160°E	1992, Long March	
ARAB-SAT (ig 19.4)	1	Aerospatiale	Spacebus 200	3-Axis	25 C-band	7	19°E	Feb 85 Ariane	It is a 22-nation Arab project established in mid 1970's to provide TV and Telecommunication services to its member countries.
	2	Aerospatiale	Spacebus 200	3-Axis	25 C-band	7	26°E	Jun 85 STS	
	3	Aerospatiale	Spacebus 200	3-Axis	25 C-band	7	-	-	

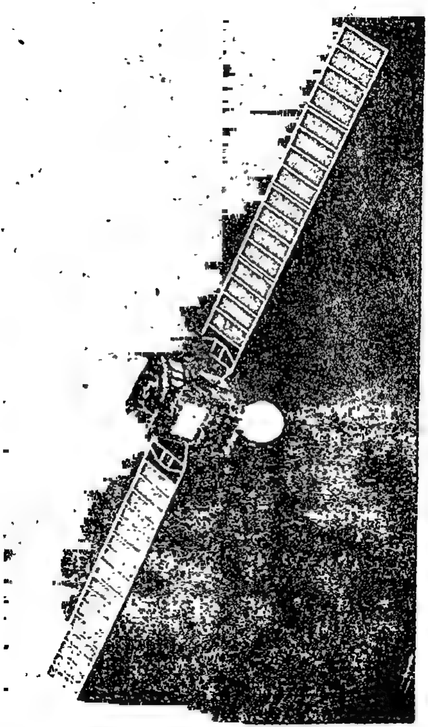


Fig 19.4

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilisation*	*Paylsad*	*Design Life,Yrs*	*Location*	*Launch*	*Brief Description*
BRASIL-SAT	S1	Spar Aerospace	HS-376	Spin	24 C-Band	10	65°W	Feb 85, Ariane	BRASILSAT satellites provide national telephony, TV, military and high speed data links.EMBRA-TEL(the owner) is also offering transponders to other latin American countries.
	S2	Spar Aerospace	HS-376,	Spin	24 C-Band	10	70°W	March 86, Ariane	
ASC	1	GE Astro	Satcom 3000	3-Axis	18 C-band, 6 Ku-band	10	128°W	Aug 85, STS	These satellites are operated by American satellite, a subsidiary of continental Telecom(Contel). The ASC satellites offer voice, data facsimile and video services, The option for the third satellite was not taken up and ASC-3 became panAm Sat (PAS) 1
	2	GE Astro	Satcom 3000	3-Axis	18 C-band, 6 Ku-band	10	70-40°W	March 91, Delta	
	3	Option sold to Aapha lyracom as PAS-1	-	-	-	-	-	-	

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*BUS*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
Comstar (Fig. 19 5)	D2	Hughes	INTELSAT-IV	Spin	24C-band	7	76^{o}W	July 76, Atlas	Operated by COMSAT,the COMSTAR satellites were leased initially to AT & T and GTE for long distance telephone communications .
	D4	Hughes	INTELSAT-IV	Spin	24 C-band	7	76^{o}W	Feb 81, Atlas	
CS (Fig 19 6)	2A	Mitsubishi	ford NATO-3	Spin	2 C-band 6 Ka-band	5	132^{o}E	Feb 83, N-II	It is the domestic communications satellite system for Japan providing mainly telephony services The satellites are operated by Japan's Telecommunications satellite. The CS-3 series includes Ka-band capacity.
	2B	Mitsubishi	Ford NATO-III	Spin	2 C-band 6 Ka-band	5	127^{o}E	Aug 83, N-II	
	3A	Mitsubishi	Ford	Spin	2C-band 10 Ka-band	7	132^{o}E	Feb 88, H-I	
	3B	Mitsubishi	Ford	Spin	2 C-band 10 Ka-band	7	135^{o}E	Sep 88, H-I	
EUTEL-SAT	ECS-1	British Aerospace	ECS	3-Axis	12 Ku-band	7	17^{o}E	June 83, Ariane	This thriving European telecommunications satellite organisation

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr*	*BUS*	*Stabilisation*	*Payload*	*Design Life, yrs*	*Location*	*Launch*	*Brief Description*
	ECS-2	British Aerospace	ECS	3-axis	12 Ku-band	7	7°E	Aug 84, Ariane	offers a ku-band regional satellite system for national postal and telecommunications monopolies to provide capacity for telephony, TV and business traffic
	ECS-4	British Aerospace	ECS	3-Axis	12 Ku-band	7	13°E	Sep 87, Ariane	
	ECS-5	British Aerospace	ECS	3-axis	12 Ku-band	7	13°E	July 88, Ariane	The Eutelsat -1 (ECS) satellites are leased to Eutelsat European space-Agency and have been now replaced by Eutelsat-II satellites system.
	Eutel-sat-II	Aerospatiale	Spacebus 100B	3-Axis	16 Ku-band	7	36°E	May90, Ariane	
	IIB	Aerospatiale	Spacebus 100 B	3-Axis	16 Ku-band	7	12°E	Nov 90, Ariane	
	II C	Aerospatiale	Spacebus 100 B	3-Axis	16 Ku-band	7	3°E	1991, Atlas	
	II D	Aerospatiale	Spacebus 100B	3-Axis	16 Ku-band	7	-	-	-

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilis-ation	Payload	Design Life,yrs	Locatioin	Launch	Brief Description
	II E	Aerospatiale	Spacebus 100 B	3-Axis	16 Ku-band	7	-	-	
BS	2 B	NEC	GE Astro SATCOM	3 Axis	2 Ku-band	4	110°E	Feb 86, N-II	This satellite system is operated by Japan Telecommunications satellite on behalf of the national TV network NHK. It was thwartedby the failure of BS-2A, the capacity of which was taken over by BS-2B to provide Japan's first DBS services to the mainland and outlying island. BS-3 series satellites are the latest in the series.
	2X	-	-	3-Axis	2 Ku-band	4	110°E	Feb 90, Ariane	
	3A	Nippon	GE Astro Satcom 3000	3-Axis	2 Ku-band	7	110°E	Sep 90, H-I	
DFS KOPER-NIKUS	1	DFS Consortion	DFS	3-Axis	10 Ku-band, 1 Ka-band	10	24°E	May 29, Ariane	This Deutsche Bundepost Government funded project was ostensibly with an export base for satellites. The capacity on these large satellites to provide telephony.

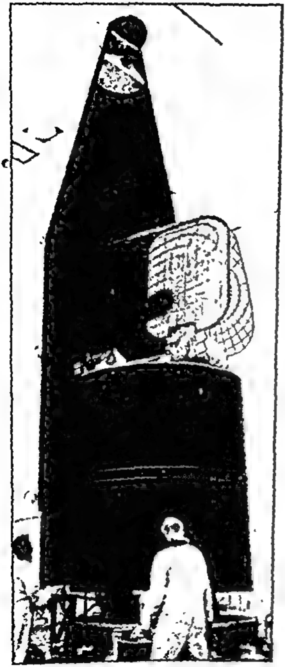


Fig. 19.5

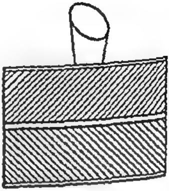


Fig. 19.6

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Locatoin*	*Launch*	*Brief Description*
	2	DFS Consortium	DFS	3-Axis	10 Ku-band 1 Ka-band	-	28°E	-	business communications and cable television channel distribution is underused.
	3	DFS Consortium	DFS	3-Axis	10 Ku-band 1 Ka-band	-	-	-	
GALAXY	1	Hughes	HS-376	Spin	24 C-band	10	134°W	Jun 83, Dara	Hughes Communications GLAXY provides C-band domestic voice, data and video traffic in U.S A. using Galaxy 1-3 satellites followed by three ku-band satellites (Galaxy 4-6) to provide coporate voice and data broadcasting and TV, financial information services and videoconferencing
	2	Hughes	HS-376	Spin	24 mC-band	10	74°W	Sep 83,	
	3	Hughes	HS-376	Spin	24 mC-band	10	93°W	Sep 84, Data	
	4	Hughes	HS-376	Spin	16 Ku-band	10	99°W	1991, Atlas	
	5	Hughes	HS-376	Spin	16 Ku-band	10	125°W	1992, Atlas	
	6	Hughes	HS-376	Spin	16 Ku-band	10	91°W	July 90, Ariane	

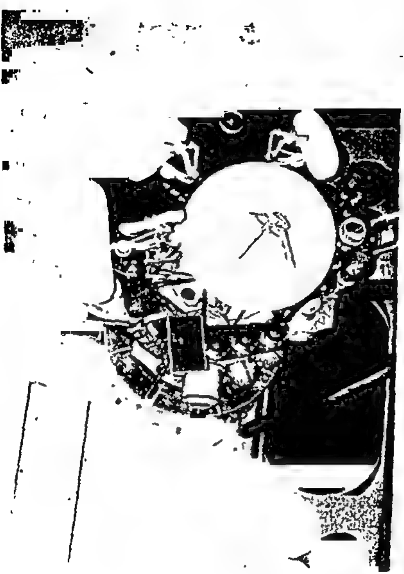


Fig 19.7

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*BUS*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
GSTAR	1	GE-Astro	SATCOM 3000	3-Axis	16 Ku-band	10	103°W	May 85, Ariane	G-STAR satellites provide voice, and Data comm-unications services offering further services to the U S.A. and replacing those originally offered by the COMSAT Comstar satellites
	2	GE-Astro	SATCOM 3000	3-Axis	16 Ku-band plus Geostar Link 1	10	105°W	March 86, Ariane	
	3	GE-Astro	SATCOM 30000	3-Axis	16 Ku-band plus Geostar Link-1	10	93°W	Sep 88, Ariane	
	4	GE-Astro	SATCOM 3000	3-Axis	16 Ku-band plus Geostar Link-2	10	136°W	Aug 90, Ariane	

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr	Bus	Stabilisation	Payload	Design Life,yrs	Location	Launch	Brief Description
GEOSTAR	1	[illegible]	[illegible]	3-Axis	L-band C-band S-band	10	70°W	1991	It is a US privately funded radio determination satellite service Geostar is also a share holder in the Lockstar European RDSS system.
[illegible]	12		Gorizont	3-Axis	6 C-band 1 Ku-band, 1 L-band	3	40°E	June 86Proton	These Soviet Communications satellites have been offered for commercial use in the west
	13		Gorizont	3-Axis	6 C-band 1 Ku-band, 1 L-band	3	90°E	Nov 86, Proton	
	14		Gorizont	3-Axis	6-C-band 1 Ku-band, 1 L-band	3	102°E	May 87, Proton	
	15		Gorizont	3-Axis	6C-band 1 Ku-band 1L-band	3	14°E	March 88, Proton	

Table 19.1. Communication Satellites (Contd.)

Satellit	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
	16	-	Gorizant	3-Axis	6 C-band 1 Ku-band 1 L-band	3	80°E	Aug 88, Proton	–
	17	-	Gorizont	3-Axis	6 C-band 1 Ku-band 1L-band	3	53°E	June 89, Proton	
HISPA-SAT	1	Matra	Eurostar	3-Axis	4 Ku-band 8 C-band2 S-band	10	31°W	1992 Ariane	It was a Spanish government funded programme to support TV coverage of the olympic games in Barcelona in 1992 and to provide a wide range of national communications services.
	2	Matra	Eurostar	3-Axis	4 Ku-band 8 C-band 2 S-band	10	31°W	1992 Ariane	
	3	Matra	Eurostar	3-Axis	4 Ku-band 8 C-band 2 S-band	10	-	-	
INMAR-SAT	II-F1	British Aeroshpace	Eurostar	3-Axis	4 C-band 2 L-band	10	155°W		INMARSAT is the satellite system of the International Maritime communication s organisation comprising 50 member countries. It provides a
	F2	British Aerospace	Eurostar	3-Axis	4 C-band 2 L-band	10	65°E	Feb 91, Ariane	

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilisation*	*Payload*	*Design Life,yrs.*	*Location*	*Launch*	*Brief Description*
	F3	British Aerospace	Eurostar	3-Axis	4 C-band 2 L-band	10	180°E	July 91, Ariane	core market of over 50[illegible] sea going vessels with communication services. It is developing a much wider mobile communications market using *future dedicated* satellites. There are options for up to nine Inmarsat IIs and the planned Inmarsat-3 fleet could also number 9
	F4	British Aerospace	Eurostar	3-Axis	4 C-band 2 L-band	10	55°N	Nov 92, Ariane	
	F5	British Aerospace	Eurostar	3-Axis	-	-	-	-	
	F6-F9	British Aerospace	Eurostar	3-Axis					
INSAT (Fig 19.8)	1B	Ford Aerospace	INSAT-1	3-Axis	2 S-band 1 C-band	7	74°E	Aug 83, STS	INSAT is a satellite project of the Goverment of India operated by ISRO, Department of space. It is a multipurpose communication and meteorological satellite system providing TV traffic, telephony, meteorology, radio and private network services
	1C	Ford Aerospace	INSAT-1	3-Axis	2 S-band 1 C-band	7	93°E	July 88, Ariane	

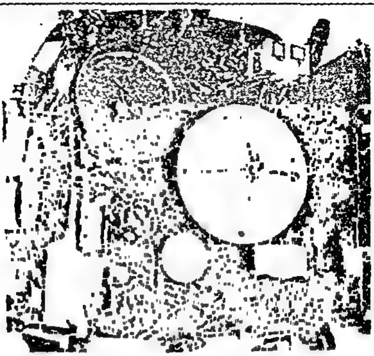


Fig. 19.8

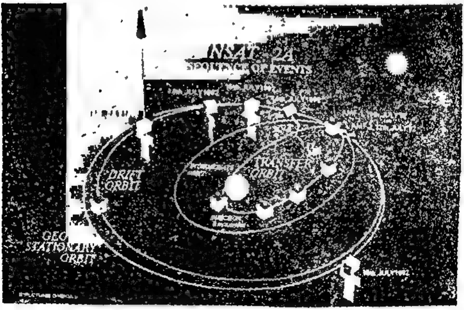


Fig 19 9

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
	1D	Ford Aerospace	INSAT-I	3-Axis	2 S-band 1 C-band	7	83°E	22June 90, Delta	
	2A	ISRO	INSAT-I	3-Axis	18C-band 2S-band	7	74°E	1992, Ariane	
	2B	ISRO	INSAT-I	3-Axis	18C-band 2 S-band	7	-	1994 Ariane	–
	2C	ISRO	INSAT-I	3-Axis	-	-	-	1995	
	2D	ISRO	INSAT-I	3-Axis	-	-	-	1996	
	2E	ISRO	INSAT-I	3-Axis	-	-	-	1997	–
Intelsa (Fig 19 9)	V F1	ford Aerospace	Intelsat-V	3-Axis	21C-band 6 ku-band 2 L-band	9	177°E	May 81, Atlas	The Iternation Telecommunications Satellite Organisation, INTLSAT with more than 100 members world-wide provides satellite capacity formember countries Post, Telegraph and Telecommunications (PTT) organisations and had a near monopoly until recently when competitive systems such as PanAm Sat (PAS) were given
	F2	Ford Acrospace	Intelsat-V	3-Axis	21C-band 6Ku-band 2 L-band	9	21°W	Dec 80, Atlas	
	F3	Ford Aersopace	Intelsat-V	3-Axis	21C-band 6Ku-band 2L-band	9	174°E	Dec 81, Atlas	

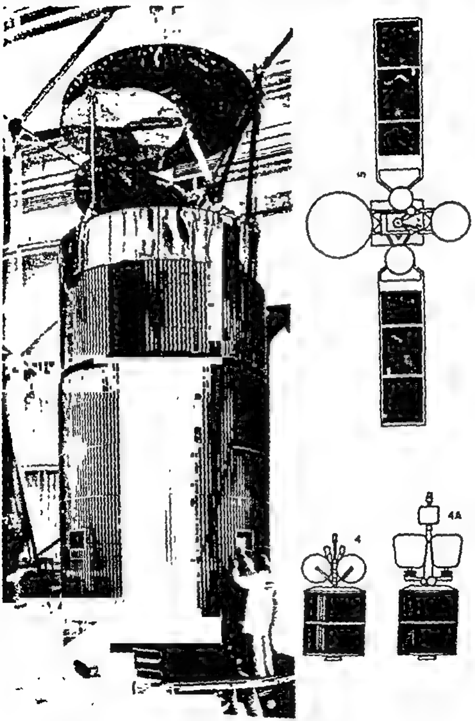


Fig 19.9

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*BriefDescription*
	F4	Ford Aerospace			21C-band6 K2L-band	9	35°W	March 82, Atles	approval from the FCC INTELSAT-VI is the most recent in the series All INTELSAT-IV have retired INTELSAT-V are to now replaced by INTELSAT-VII. A new satellite, Intelsat-K is a rapid response venture to comptitive systems to provide dedicated Ku-band services using the second hand system Satcom K4
	F5	Ford Aerospace	Intelsat V	3-Axis	21 C-band 6 Ku-band 2L-band	9	63°E	Sep 82, Atlas	
	F6	Ford Aerospace	Intelsat-V	3-Axis	21 C-band 6 Ku-band 2L-band	9	18°W	May 83, Atlas	
	F7	Ford Aerospace	Intelsat-V	3-Axis	21 C-band 6 Ku-band 2L-band	9	66°E	Oct 83, Atlas	–
	F8	Ford Aerospace	Intelsat-V	3-Axis	21 C-band 6 Ku-band 2L-band	9	180°E	May 84, Ariane	–
	V-A F10	Ford Aerospace	Intelsat-V	3-Axis	32 Ku-band 6 Ku-band	9	24°W	March 85, Atlas	–
	F11	Ford Aerospace	Intelsat-V	3-Axis	32 Ku-band 6 Ku-band	9	27°W	June 85, Atlas	

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilisation	Payload	Design Life,yrs	Location	Launch	Brief Description
INTEL-SAT	VA F12	Ford Aerospace	Intelsat-V	3-Axis	32 C-band 6 Ku-band	13	1°W	Sep 85, Ariane	–
	VB F13	Ford Aerospace	Intelsat-V	3-Axis	32 C-band 6 Ku-band	13	53°W	May 88, Ariane	–
	F15	Ford Aerospace	Intelsat-V	3-Axis	32 C-band 6 Ku-band	13	60°E	Jan 89, Ariane	–
	VI-F1	Hughes	Intelsat-VI	spin	36 C-band 10 Ku-band	13	37°W	Oct 89, Ariane	–
	F2	Hughes	Intelsat-VI	spin	36 C-band 6 Ku-band	13	Atlantic	1990, Titan	–
	F3	Hughes	Intelsat-VI	spin	36 C-band 6 Ku-band	13	Indian	1990, Titan	–
	F4	Hughes	Intelsat-VI	spin	36 C-band 6 Ku-band	13	Atlantic	1991, Ariane	–
	F5	Hughes	Intelsat-VI	spin	36 C-band 6 Ku-band	13	Indian	1991, Ariane	–
	VII-F1	Ford Aerospace	Intelsat-VII	3-Axis	26 C-band 10 Ku-band	15	Pacific	1992, Ariane	–

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
	F2	Ford Aerospace	Intelsat-VII	3-Axis	26 C-band 10 Ku-band	15	Pacific	1993, Ariane	
	F3	Ford Aerospace	Intelsat-VII	3-Axis	26 C-band 10 Ku-band	15	Atlantic	1993, Ariane	
	F4	Ford Aerospace	Intelsat-VII	3-Axis	26 C-band 10 Ku-band	15	Atlantic	1994, Ariane	
	F5	Ford Aerospace	Intelsat-VII	3-Axis	26C-band 10 Ku-band	15	Atlantic	1994, Ariane	
	K	GE Astro originally	SATCOM 5000	3-Axis	16 Ku-band	10-15	130-158°W	1991, Atlas	
LOC STAR	1	Matra	Eurostar	3-Axis	3C/S Band 3L/C band	10-15	5°W	1992	This is an international consortium led by French space Agency CNES to provide an RDSS for Europe, Africa and the middle east. RDSS stands for Radio Determination Satellite Service.
	2	Matra	Eurostar	3-Axis	3C/S band 3 L/C band	10-15	20°E	1992	
JC SAT	1	Hughes	HS-376	spin	32 Ku-band	10	150°E	March 89, Ariane	It is a joint venture between Hughes communications and the Japnese companies, Itoh and Mitsu, to provide

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
	2	Hughes	HS-376	spin	32 Ku-band	10	154°E	June 90, Titan	Ku-band domestic services to overcome shortcomings of Government funded CS-2 and 3 projects and in competition with the Ford Aerospace backed Superbird satellites project
Marco polo	1	Hughes	HS-376	Spin	3 Ku-band	10	31°W	Aug, 89, Delta	It is a British Satellite Broadcasting's(BSB) satellite system to operate UK's domestic broadcast service (DBS) TV system
	3	Hughes	HS-376	Spin	3 Ku-band	10	31°W	Aug 90, Delta	
Marisat (Fig 19.10)	1	Hughes		Spin	1 L-band 1 C-band 1 UHF	5	15°W	Feb 76, Delta	These satellites, operated by COMSAT, are now inorbit spares for Inmarsat. These satellites were used initially for the U.S Maritime Association.
	2	Hughes		Spin	1 L-band 1 C-band 1 UHF	5	72°E	June 76 Delta	
	3	Hughes		Spin	1 L-band 1 C-band 1 UHF	5	176°E	Oct 76, Delta	

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilis-ation	Payload	Design Life,yrs	Location	Launch	Brief Description
ITAL-SAT	1	Selenia Spazio	ECS/Italsat	3-axis	16 Ku-band	10	13°E	Dec 90, Ariane	This national communications satellite, to be operated by telespazio on behalf of Italian space Agency ostensibly a preoperational experimental spacecraft but may be used commercially in some areas. It will provide PTT services and national TV.
MORE-LOS	A	Hughes	HS-376	Spin	18 C-band 4 Ku-band	9	113°W	June 85, STS	It is the Mexican satellite system. It uses Hughes satellites and provides telephony and television services. Mexico envisages its use for health, family planning and agricultural education.
	B	Hughes	HS-376	Spin	18 C-band 4Ku-band	9	117°W	Nov 86, STS	
OLYM-PUS Fig. 19.11	1	British Aerospace	Olympus	3-Axis	2 DBS 3 Ku-band 4 Ka-band	9	19°	July 89, Ariane	It is an ESA funded satellite. It is an experimental/R&D spacecraft but does have commercial applications such as educational and national TV.
ORION	1	British Aerospace	Eurostar	3-Axis	34 Ku-band	10	47°W	1992, Atlas	Originally established in 1983 to competewith INTELSAT in

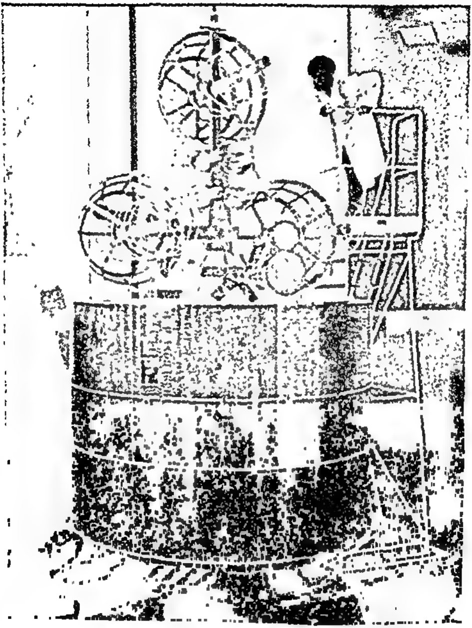


Fig. 19.10

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilis-ation	Payload	Design Life,yrs	Location	Launch	Brief Descriptio
	2	British Aerospace	Eurostar	3-Axis	34 Ku-band	10	37°W	1992, Atlas	the Atlantic region, the orion satellite venture finally ordered two Ku-band satellites from British Aerospace in 1989. BAe is a member of the Orion company and has formed a joint company, BAe-Tel with a Government license to provide domestic service in U.K.
PALAPA	B1	Hughes	HS-376	Spin	24 C-band	8	108°E	June 83, STS	Palapa is a C-band system providing PTT telephony TV, Radio and Govern-ment communications service to the Indonesian mainland. The system has been leased to phillipines, Malaysia and Thailand.
	B2P	Hughes	HS-376	Spin	24 C-band	8	113°E	March 87, Delta	–
	B2R	Original Palopa B2	HS-376	Spin	24 C-band	8	118°E	March 90, Delta	–

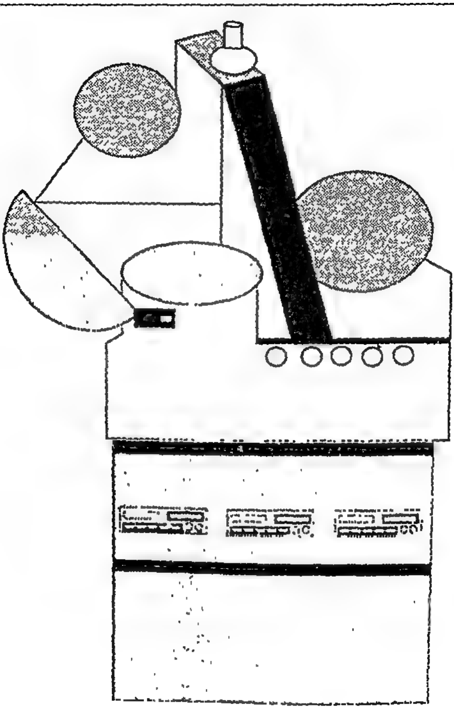
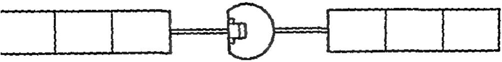


Fig. 19.11

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Descriptio*
SATCOM (Fig.19.12)	III-R	GE Astro	Satcom 3000	3-Axis	24 C-band	8	131°W	Nov 81, Delta	Originally operated by RCA American communications, the SAT-COM fleet is now owned by GEAstro. SATCOM was the second U.S domestic satellite communications sistem after Westar. It offers C-band and Ku band services for TV distribution in the U.S.A.
	IV	GE Astro	Satcom 3000	3-Axis	24 C-band	8	84°W	June 82, Delta	
	V	GE Astro	Satcom 3000	3-Axis	24 C-band	8	143°W	Oct 82, Delta	–
	VI-IR	GE Astro	Satcom 3000	3-Axis	24 C-band	8	139°W	April 83, Delta	–
	VII-IIR	GF AstroGE Astro	Satcom 3000	3-Axis	24 C-band	8	72°W	Sep 83, Delta	–
	VIII	GE Astro	Satcom 3000	3-Axis	24 C-band	8	136° W	1990, Ariane	–
	IX (C3)	GE Astro	Satom 3000	3-Axis	24 C-band	8	131° W	1992, Ariane	–



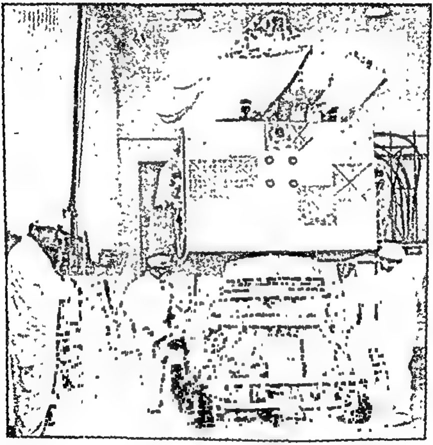


Fig. 19.12

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Descriptio*
	X (C4)	GE Astro	Satcom 3000	3-Axis	24 C-band	8	-	1993 Ariane	-
	K1	GE Astro	Satcom 3000	3-Axis	16 Ku-band	10	85°W	Jan86, STS	-
	K2	GE Astro	Satcom 3000	3-Axis	16 Ku-band	10	81° W	Nov 85, STS	-
	K3	GE Astro	Satcom 3000	3-Axis	16 Ku-band	10	-		-
	K4	GE Astro	Satcom 3000	3-Axis	16 Ku-band	10	130-158° W	1991 Atlas	-
PAS	1	GE Astro (original ASC-3 sold to Alpha lyracom)	Satcom 3000	3-Axis	18 C-band, 8 Ku-band	11	45°W	June 88, Ariane	Pan American Satellite (PAS), owned by Alpha Lyracom which is headed by a spanish entrepreneur, operates the first satellite to compete with the Intelsat monopoly providing low cost specialised services to north America, Europe and Latin America.

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*BUS*	*Stabilisation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
SBS (Fig.19.13)	1	Hughes	HS-376	Spin	10 Ku-band	7	99^0 W	Nov 80, Delta	Satellite Business Systems (SBS) was formed by IBM. Comsat and Aetna invested one billion dollars in a high speed digital data transmission- business service on SBS-1 to 5. SBS-1 and 2 are now owned by Comsat and SBS-3,4 and 5 by MCI.
	2	Hughes	HS-376	Spin	10 Ku-band	7	99^0 W	Sep 81, Delta	
	3	Hughes	HS-376	Spin	10 Ku-band	7	91^0 W	Nov 82, STS	
	4	Hughes	HS-376	Spin	10 Ku-band	7	122^0 W	Aug 84, Delta	
	5	Hughes	HS-376	Spin	10 Ku-band	7	99^0 W	Sep 88, Ariane	-
	6	Hughes	HS-376	Spin	9 Ku-band Ku-band	15		June 90, Ariane	-
SPACENET	1	GE Astro	Satcom	3-Axis	12 C-band 12 KU-band	10	120^0W	May 84, Ariane	These satellites are the second in fleet operated by GTE spacenet and are used for video distribution and business traffic, primarily GTE's own sprint service
	2	GE Astro	Satcom	3-Axis	12 C-band 12 Ku-band	10	69^0W	Nov 84, Ariane	
	3R	GE Astro	Satcom	3-Axis	12 C-band 12 Ku-band plus Geostar Link 2 payload				

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilis-ation	Payload	Design Life,yrs	Location	Launch	Brief Desription
Superbird	A	Ford Aerospace	Supersat	3-Axis	12 Ku-band 23 Ka-band	10	158°W	June 89, Auiane	These satellites are operated by space communi-caations of Japan, which is compe ting with JC SAT to provide cable TV, video conferencing, teleph-hony, newspaper transmission, business applications, banking and other services It was established with backing from Ford Aerospace which prov-ides supersat satellite bus
	B	Ford Aerospace	Super-sat	3-Axis	12 Ku-band 23 Ka-band	10	-	Feb 90, Ariane	
TDF	1	Aerospatiale	Space-bus300	3-Axis	5 Ku-band	9	19°W	Oct 88, Anane	This is the French equivalent of West Ger-man TV-SAT.
	2	Aerospatiale	Space bus300	3-Axis	5 Ku-band	9	19°W	March 90, Anane	
TELECOM	1A	Matra	LCS	3-Axis	6 Ku-band 4 C-band 2 X-band	7	8°W	Aug 84, Ariane	France's domestic tele-communications satellite system owned by the

Table 19.1. Communication Satellites (Contd.)

Satellite	No.	Mfr.	Bus	Stabilisation	Payload	Design Life, yrs	Location	Launch	Brief Description
[illegible]	[illegible]	Matra	TCS	3-Axis	6 Ku-band 4 C-band 2 X-band	7	140°E	May 85, Ariane	France PTT and French space agency CNES, provides TV, telephone, digital data commun-ications and also a military channel called syracuse, covering home and overseas territories. The system is operated by France cables et Radio.
	[illegible]	Matra	[illegible]	[illegible]	6 ku-band 4 C-band, 2 X-band	7	5°W	March 88, Ariane	
	[illegible]	Matra	[illegible]	[illegible]	11 ku band 10 C-band, [illegible] X-band	10	5°W	1992, Ariane	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Hughes	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–
	[illegible]	Hughes	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	This is the AT & T [illegible]

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Desription*
Superbird	A	Ford Aerospace	Supersat	3-Axis	12 Ku-band 23 Ka-band	10	158°W	June 89, Auiane	These satellites are operated by space communi-caations of Japan, which is competing with JC SAT to provide cable TV, video conferencing, telephony, newspaper transmission, business applications, banking and other services It was established with backing from Ford Aerospace which provides *supersat satellite* bus
	B	Ford Aerospace	Super-sat	3-Axis	12 Ku-band 23 Ka-band	10	-	Feb 90, Anane	
TDF	1	Aerospatiale	Space-bus300	3-Axis	5 Ku-band	9	19°W	Oct 88, Anane	This is the French equivalent of West German TV-SAT
	2	Aerospatiale	Space bus300	3-Axis	5 Ku-band	9	19°W	March 90, Anane	
TELECOM	1A	Matra	ECS	3-Axis	6 Ku-band 4 C-band 2 X-band	7	8°W	Aug 84, Anane	France's domestic telecommunications satellite system owned by the

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilis-ation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
	1B	Matra	ECS	3-Axis	6 Ku-band 4 C-band 2 X-band	7	140°E	May 85, Ariane	France PTT and French space agency CNES, provides TV, telephone, digital data commun-ications and also a military channel called syracuse, covering home and overseas territories. The system is operated by France cables et Radio.
	1C	Matra	ECS	3-Axis	6 ku-band 4 C-band, 2 X -band	7	5°W	March 88, Ariane	
	2A	Matra	Eusostar	3-Axis	11 ku-band 10 C-band, 5 X -band	10	5°W	1992, Ariane	
	2B	Matra	Eusostar	3-Axis	11 ku-band 10 C-band, 5 X -band	10	-	1993-94	-
	2C	Matra	Eusostar	3-Axis	11 ku-band 10 C-band, 5 X -band	10	-	1993-94	-
TELSTAR (Fig.19 14)	301	Hughes	HS-376	Spin	24 C-band	10	96°W	July 83, Delta	This is the AT & T commercial domestic C-band telephonic satellite system It replaces theComstar C-band capacity.
	302	Hughes	HS-376	Spin	24 C-band	10	97°W	Aug 84, STS	
	303	Hughes	HS-376	Spin	24 C-band	10	125°W	June 85, STS	

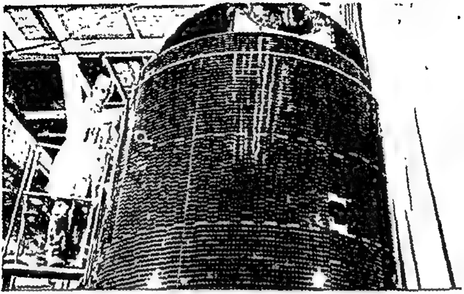


Fig 19.13

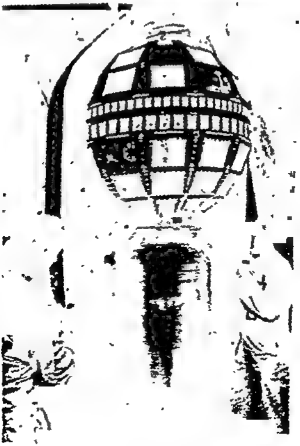


Fig. 19.14

Table 19.1. Communication Satellites (Contd.)

Satellite	*No.*	*Mfr.*	*Bus*	*Stabilisation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
	401	GE Astro	Satcom 7000	3-Axis	24 C-band	12	101-85°W	1994	–
	402	GE Astro	Satcom 7000	3-Axis	24 C-band	12	101-85°W	1994	–
	403	GE Astro	Sacom 7000	3-Axis	24 C-band	12	101-85°W	1995	–
TELEX	1	Aerospatiale	Space-bus100	3-Axis	3 ku-band 4 C-band	7	5°E	April 89, Ariane	This is the Scandinavian version of TDF and TV-Sat DBS satellites It is operated by Notelsat Originally a Swedish project, has been joined by Norway, Finland, Iceland and Denmark.
TV-SAT (Fig 19.15)	1	MBB	Aerospatiale space-bus-300	3-Axis	4 ku-band	7	19°W	Nov 87, Ariane	This is the West German DBS satellite system operated by Deutsche Bundepost

Table 19.1. Communication Satellites (Contd.)

Stellite	*No.*	*Mfr.*	*Bus*	*Stabilisation*	*Payload*	*Design Life,yrs*	*Location*	*Launch*	*Brief Description*
WESTAR	IV	Hughes	HS-376	Spin	24 C-band	10	99^0 W	Feb 82, Delta	Westars were the first domestic US communications satellites, launches starting in 1974, after the FCC decision to proceed with DOMSAT. The satellite provides domestic C-band capacity, which includes voice and data traffic as TV distribution services
	V	Hughes	HS-376	Spin	24 C-band	10	122^0 W	June 82, Delta	
	VI	Hughes	HS-376	Spin	24 C-band	10	105-116^0 W	April 90, Long March	–
	VI-S	Hughes	HS-376	Spin	24 C-band	10	79^0 W	-	

Fig. 19.15

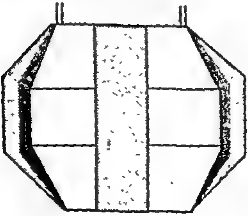


Fig. 19.16

Table 19.2. Satellites for Earth Observation

Satellite	*Stabilis-ation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
Bhas-kara-I (Fig.19.16)	Spin	-	-	535 Km inclined at 50.7°	June, 1979 Intercosmos Rocket	Also known as Satellite for Earth observation (SEO) Bhaskara-1 retired in Aug 1981 when its attitude control fuel was exhausted. The satellite resembles an octagonal section covered with solar cells. Bhaskaras were some of the first satellites built by India.
Bhas, kara-II	Spin	-	A television camera operating in visible and infrared plus a microwave imaging system.	-	Nov, 1981 Intercosmos Rocket	
ERS-1 (Fig.19.17)	3-Axis	Plus 2 years	*Synthetic Aperture* Radar (SAR) combined with wind scatterometer + radar altimeter	Sun Sync., 780 Km high	*1987, Ariane 3*	*Manufactured* by Dornier and owned by ESA, ERS-1 is Europe's first Earth Resources Satellite designed for ocean *monitoring*. Though a European space agency venture, Canada is involved to the *tune* of almost 10 per cent It uses multimission bus developed by France for *SPOT* Yaw steering for improved image quality and large fuel supply for orbit manoeuvring are other features.

Table 19.2. Satellites for Earth Observation (Contd.)

Satellite	*Stabilis-ation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
IRS-1A (Fig.19.18)	-	3-yrs	Cameras LISS I and LISS-II	Polar Sun synchronous 904 km high	March, 1988 VOSTOK	IRS-1A and 1B are the mainstay of the National Natural Resources Management system for providing remote sensing data services to various users
IRS-1B	-	3-yrs	Came as LISS-I and LISS-II	Sun synchro-nous, 904 km high	August, 1991	
IRS-1C	-	-	Cameras with resolution better than that of LISS-I and LISS-II	-	1994-95	
IRS-1D	-	-	and having stereo viewing	-	1996-97	
IRS-1E	-	-	LISS-I Monocular	-	-	
IRS-2A/2B	-	-	-	-	1998-99	
MOS-1	3-Axis	2	Multispectral electronic self scanning radiometer + visible and	Sun Synchornous ,910 Km high	1986, N-2	MOS-1 is Japan's first earth observation satellite. It is an experimental satellite aimed at establishing the technology for an

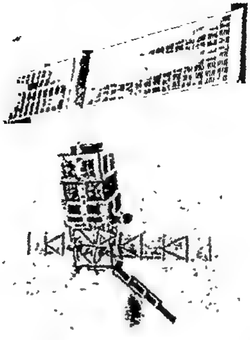


Fig. 19.17

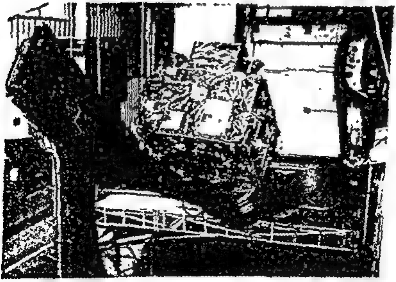


Fig. 19.18

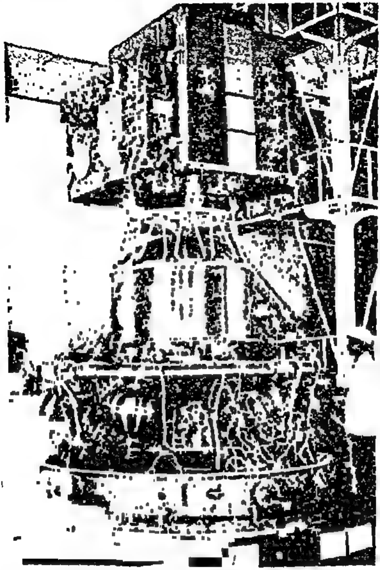


Fig. 19.18 (Contd.)

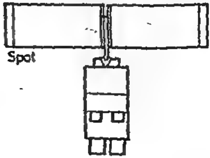


Fig. 19.19

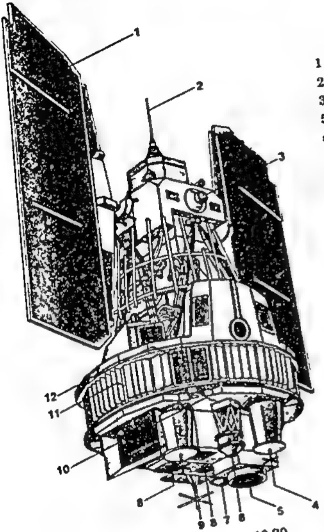
Table 19.2. Satellites for Earth Observation (Contd.)

Satellite	*Stabilisation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
			thermal infrared radiometer + microwave scanning radio meter + Data collection transponder	and inclined 99.1° Repeat cycle is 17 days		operational system. Observing sea surface and atmosphere are the goals.
SPOT (Fig. 19.19)	3-Axis	2	Two identical high resolution visible imaging instruments. Each sees in visible or infrared in one of two modes-panchromatic or multispectral. Resolution in panchromatic mode is 10m and in mullispectral mode is 20m.	Sun synchronous 832 Km high circular and inclined at 97.7°, Repeat cycle is 26 days	Jan 1985, Ariane	It is France's first earth observation satellite designed to monitor land resources such as crops, forests. Data obtained from SPOT is to be made available commercially through a new company called spot image.

Table 19.2 : Satellites for Earth Observation (Contd.)

Satellite	[illegible]	[illegible]	Payload	Orbit	Launch	Other Features
Landsat-1	S-Axis		Multispectral Scanner			LANDSAT series satellites are the earth observation satellites from [illegible] LANDSAT-4 and LAND[illegible] [illegible] an advanced LANDSAT-6 craft which will be based on the flight proven DMSP/Tiros weather satellite design.
Landsat-2	S-Axis		Multispectral Scanner			
Landsat-3 (Fig.19.20)	S-Axis		Multispectral Scanner			
Landsat-4	S-Axis	S	Multispectral Scanner + Thematic Mapper	Sun Synchronous, 705 Km high and inclined at 98°. Repeat cycle is 16 days	July 19[illegible], Delta 39[illegible]	
[illegible]	[illegible]	S	Multispectral Scanner + Thematic Mapper		March 1984, Delta 3920	

pictures [illegible]
minutes + space
environment



1 Solar Panel
2 Command antenna
3 Wide band antenna
5 Five band multi spectral scanner
6 Unified S band antenna
7. Attitude measurement sensor
8. Return beam vidicon cameras (2)
9 Data collection systems antenna
10 ERTS command auxil lary memory (ECAM) subsys tem
11 Sensory ring
12 Beacon antennas (4)

Fig. 19.20

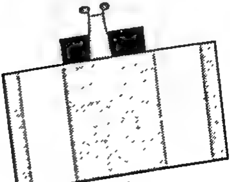


Fig. 19.21

Table 19.3. Weather Satellites

Satellite	*Stabilisation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
GMS-1 (Fig 19.21)	Spin	3	Visible / Infrared spin scan radiometer producing pictures of earth every 30 minutes + space environment	Geostation-ary 140°E	July, 1977 Delta	Geostationary Meteorological Satellite (GMS) is a series of meteorological satellites built by Hughes for Japan. GMS-1 GMS-2, GMS-3A and GMS-3B are the satellites in series. The GMS-series satellites have a shorter bus.
GMS-2	Spin	3	Visible / Infrared spin scan radiometer producing pictures of earth every 30 minutes + space environment	Geostation-ary 140°E	August, 1981 N-II	
GMS-3A	Spin	3	Visible / Infrared spin scan radiometer producing pictures of earth every 30 minutes + space environment	Geostation-ary	September 1984 N-II	
GMS-3B	Spin	3	Vinble / Infrared spin scan radioneter producing pictures of earth evry 30 minutes + space environment	Geostation-ary	1989 N-II	

Table 19.3. Weather Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life,yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
GOES-1	Spin	7	Visible / Infrared spin / scan radiometric atmospheric sounder (RAS). Resolution of 0.9 Km in visible light and 6.9 Km in infrared. Other equipment includes data collection / relay system and a space environment monitor (GOES-1 to GOES-8)	Geostationary 135°W (GOES-4) and GOES-6) 75°W (GOES-5) 83°W (GOES-8)	Oct 1975 (GOES-1) June 1977 (GOES-2) June 1978 (GOES-3) Sep 1980 (GOES-4) May 1981 (GOES-5) April 1983 (GOES-5) 1986 (GOES-6)Feb 1987 (GOES-8) All launches from Delta	GOES (Geostationary Operational Environmental Satellite) is one of the two main elements in America's weather coverage. The other is polar orbiting TIROS-N-series. GOES-I to GOES-M are an advanced series of satellites ordered from Ford aerospace.
2	Spin	7.				
	Spin	7				
3	Spin	7				
4	Spin	7				
5	Spin	7				
6	Spin	7				
7	Spin	7				
8	Spin	7				
GOES-I	Spin	-				
J	Spin	-				
[illegible]	Spin	-				
[illegible]	Spin	-				
[illegible]	Spin	-				

Table 19.3. Weather Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
INSAT (Fig.19.22)	-	-	Very High Resolution Radiometer (Payload for weather role)	Geostationary	-	INSAT-series satellites are multi-purpose satellites that combine direct broadcast, communications and weather roles.
METEO-SAT-1 (Fig.19.23)	Spin	3	Radiometer operating in the visible, infrared and water vapour spectrum (A complete picture is produced every 30 minutes) + Data collection system (For METEOSAT-1 and METEOSAT-2)	Geostationary 0° longitude (METEO-SAT-1) and Geostationary 10°E (METEO-SAT-2)	Nov 1977, Thor-Delta	METEOSAT-series weather satellites are owned by European Space Agency and manufactured by Aerospatiale. Meteosat's main roles include production of weather pictures and relay of data from remote sites.
METEO-SAT-2	Spin	3			June, 1981 Ariane	
TIROSN / NOAA (Fig.19.24)	3-Axis	-	Advanced very high resolution radiometer, high resolution infrared	Sun synchronous and	All launches are by Altas E/F. NOAA-6 in 1979.	It is the polar-orbiting element of America's weather satellites. (GOES in geostationary orbit is the other).

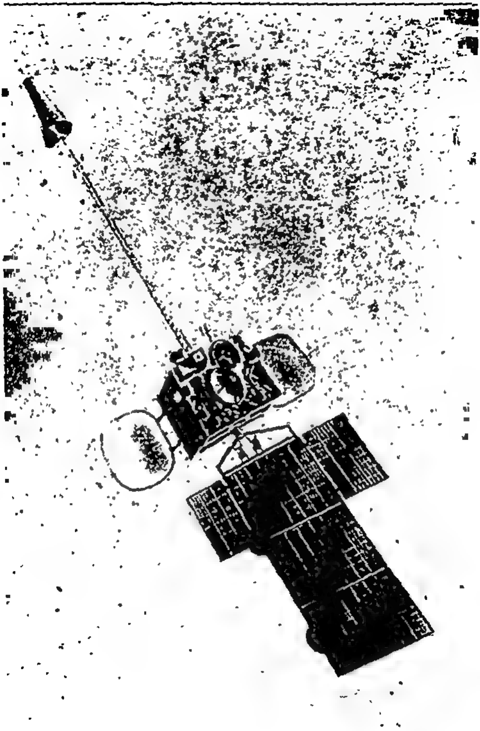


Fig 19 22

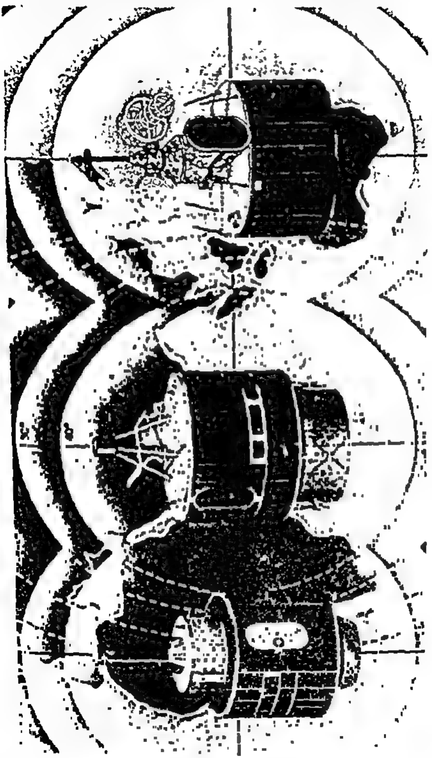


Fig. 19.23

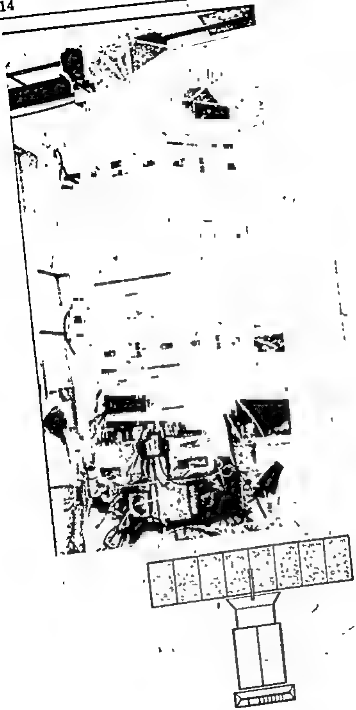


Fig. 19.24

Table 19.3. Weather Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life,yrs*	*Payload*	*Orbit*	*Launch*	*Other Fcaatures*
			sounder, stratospheric sounding unit, Microwave sounding unit and data collection system. Space Environment Meter (SEM) and Search and Rescue payload Some advanced TIROS-N satellites carry solar Backscather Ultraviolet Instrument, Some satellites also carry Earth Radiation Budget Experiment payload	inclined at 98 9°	NOAA-7 in 1980 and NOAA-8 in 1983	It Comprisesof a series of eight satellites, the first of which was TIR-OSN launched in October 1978 and deactivated in Feb 1981. The next craft is called NOAA-6 and so on through to NOAA-12 NOAA-C through NOAA-1 before launch). The operational network comprises two craft in orthoganally intersecting orbits.
Nimbus (Nimbus-1 to Nimbus-7	3-Axis		Sensors including several pollutant sniffers and a coastal zone colour scanner	Sun Sunchronous 995 km high (Nimbus-7 called Nimbus-G before launch) Repeat cycle is 18 days	Nimbus-1 to Nimbus 7 were launched between 1964 and 1978 abroad Delta	This satellite series has served as an experimental plaform for remote sensing equipment, rather than being an operational network.

Table 19.4. Science and Technology Satellites

Satellite	Stabilis-ation	Design Life yrs	Payload	Orbit	Launch	Other Features
AMPTE / CCE / IRM	Spin	7 Months	-	CCE in a 300× 50, 000 Km orbit with 28° inclination AMPTE keeps station on IRM at a distance of about 100 Km	1984 (Thor Delta)	AMPTE (Active Magne-stosphenc Particle Tracer and Explorer) is a sub satellite of a joint venture between USA and West Germany. The US craft called Charge Compo-sition Explorer (CCE) and German Craft named Ion Release Module (IRM) All three craft are released together.
EXOSAT (Fig 19.25)	3-Axis	2	Two low energy imaging telescopes + Medium energy proportional, Counter + Gas Scintillation Spectrometer	500 Km × 200,000 Km and inclined at 72.5° Apogee is roughly above north pole	1983 (Thor Delta)	EXOSAT is Europe's first X- ray observer designed to measure the position, structural aspects and spectral and temporal characteristic of X-ray sources. Objectives also include detection of new sources and mapping of diffuse sources.
Galileo	Spin	-	Nine experiments on orbiter and six on the probe	-	1986 Space shuttle	It is US-West German joint effort to send an orbiter / Probe to an outer planet. The orbiter is des-igned to make 11 orbits of Jupiter over 20 months.

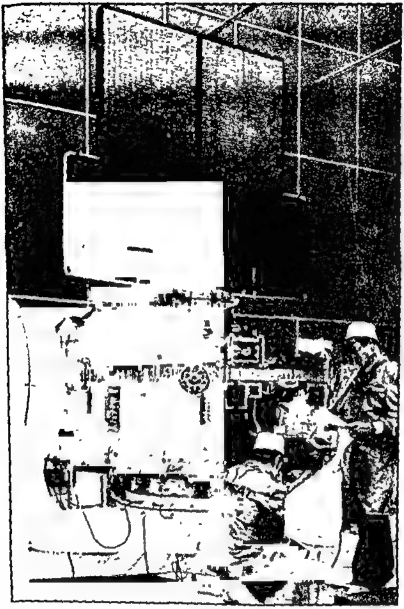


Fig. 19.25

Table 19.4. Science and Technology Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
					places Galileo and its Centaur-G prime then puts the Orbiter / Probe in to interplanatory orbit	
Gamma Ray Observ atory (GRO)	3-Axis	2	Transient event monitor + High energy gamma ray telescope + Imaging Compton telescope	400 Km high circular and inclined at 28.5°	1988 (space shuttle)	America's science and technology satellite to observe the full range of gamma rays and to see sources upto ten times fainter than those previously observed. GRO follows work done by NASA 's third high energy a astronomy observatory (HEAO).
HIPPAR-COS	Slow Spin for scanning purpose	2.5	Baker - Schmidt reflecting telescope and detectors	Near geostationary with an inclination of less than 3°	1986 (Anane)	Designed to measure accurately the positions, proper motions and parallaxes of more than 100,000 stars It is Europe's first astro-metric satellite.

Table 19.4. Science and Technology Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life,yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
Hubble-space Telescope (Fig.19.26)	-	-	-		1990 (Challenger)	Hubble Space Telescope is equipped with 2.4 m diameter *mirror which will allow observation* of stars as faint as the 27th magnitude, fifty times fainter than those seen by 0.508m Mount Palomer telescope
IRAS (Fig 19.27)	3-Axis	-	Cryogenically cooled Ritchey Chretion teles-colpe with 0.57 *m effective* operture + Low resolution spectrometer short wavelength channel and chopped photometric channel	900Km high circular	1983 (Delta 3910)	Infrared Astronomical Satellite (IRAS) is a joint venture by U.S.A., Britain and Netherlands. The objective was to perform all sky survey of *infrafed sources-free from the obscur-ing effect of earth's atmosphere.*

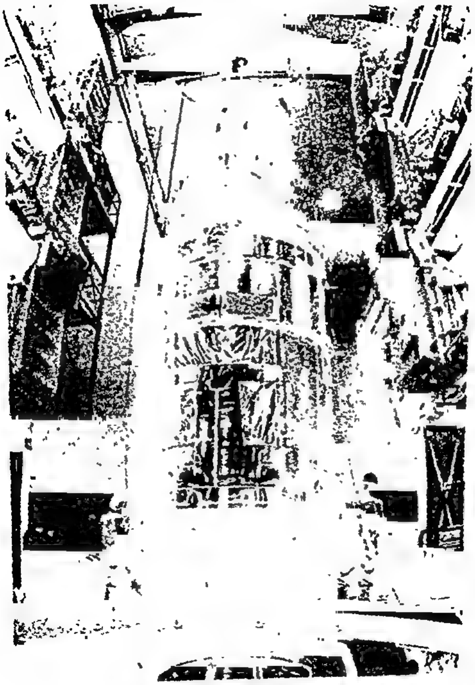
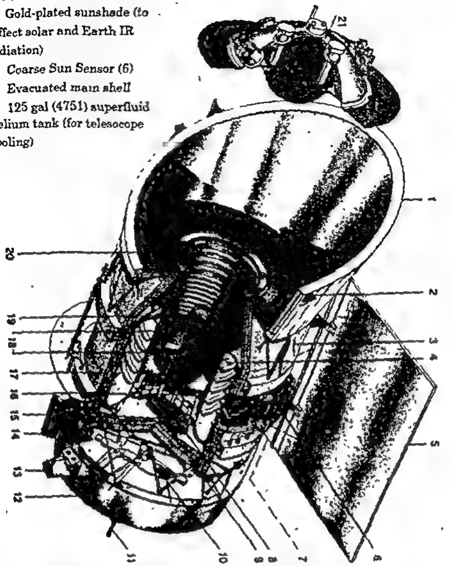


Fig 19.26

1. Gold-plated sunshade (to reflect solar and Earth IR radiation)
2. Coarse Sun Sensor (6)
3 Evacuated main shell
4. 125 gal (475l) superfluid helium tank (for telescope cooling)



5. Deployable solar panel
6. Experiment electronics
7. Fine Sun Sensor (2) (behind solar panels)
8. Dutch Additional Experiment (DAX)
9. Focal plane assembly 62 rectangular detectors
10. Cryogenic valves and manifold
11. S band antenna
12. Spacecraft telemetry attitude control and command module
13 Horizon sensor (60^{0} field of view)
14 Nickel-cadmium battery
15. DAX electronics
16. 22.4in (57 cm)
17. Mylar and Dacron net insutation
18. Baffles
19. Secondary mirror
20. Baffle
21 Helium-cooled telescope aperture cover (ejected after IRAS check-out in orbit)

Fig. 19.27

Table 19.4. Science and Technology Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life,yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
GIOTTO	Spin	1	Camera + Neutral Mass spectrometer + Ion Mass spectrometer + Dust Impact Mass spectrometer + Dust Impact detector + Electron/Ion plasma analyser + Magnetometer + Ultraviolet spectrometer.	-	1985 (Ariane-1)	Mission to observe comet Halley. GIOTTO is a European venture. It uses Geos structure model and basic design Twin sheet bumper to protec Craft from particle impact at the encounter speed of 70 Km/s
ISO	-	-	0.6 m diameter telescope cooled by liquid helium and hydrogen + Infrared camera array + spectrometers + photo meter polarimeter	-		ISO (Infrared Science Observatory) is ESA's science project intended to complement space telescope's observation in visual range. Part of ISO's time will be spent in the sky survey and the test in the detailed observations. It is more sensitive than even IRAS.
ISPM	3-Axis	-	Plasma spectometer + solar wind ion composition spectrometer + Cosmic dust	-	1986 (Shuttle)	ISPM (International Solar Panel Mission) is an ESA-NASA joint venture. It involves sending a space craft out of ecliptic plane sothat it can look down on

Table 19.4. Science and Technology Satellites (Contd.)

Satellite	*Satbilis-ation*	*Design Life,yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
			+ Magnetic field + Gamma and X-ray burst + low energy ion composition + cosmic ray and charged particle + Radio and plasma wave			sun's poles-from about the same distace as earth is now. It has sophisticated thermal control to cope with temperature extermes, autonomous operation to work around the long commucications gap, radiation hardening to withstand Jupiter worst and high reliability to cope with the long mission.
[illegible]	[illegible]	[illegible]	Nother-class telesope + High resolution imager + Wide field camera	475 Km high, circular and inclined at 57^0.	1987 (Shuttle)	ROSAT's objective was a survey of X-ray sources to be subsequently followed by detailed observation of interesting sources. The satellite was shaped like disc to minimise launch costs.
SMM (Fig [illegible])	3-Axis	1	Gamma ray spectrometer + Hard X-ray burst spectrometer + ultraviolet spectrometer and polarimeter + X-ray polychromator + Coronagraph polarimeter + active cavity irradiance monitor	500 Km high, Circular		SMM (Solar Maximum Mission)was intended to tell us more about solar flares. It was launched near the peak of sun's 2nd year sun spot cycle when disruptions are most frequent. A unique feature of this satellite was that it could the repaired in space.

Fig. 19.28

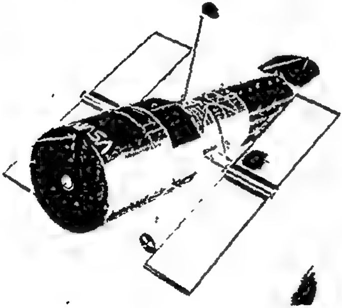


Fig. 19.29

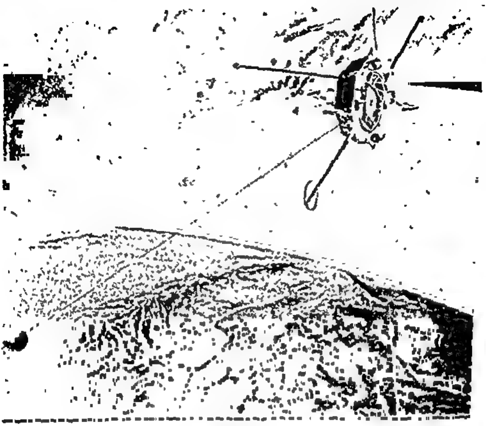


Fig. 19.30

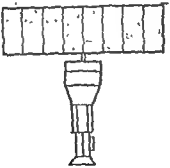


Fig. 19.31

Table 19.5. Military Satellites

Satellite	Stabilisation	Design Life, yrs	Payload	Orbit	Launch	Other features
DMSP / Block 5 D (Fig 19.31)	3-Axis	1.5	Line scanning radiometer operating in visual and infra red + Precipitating electron spectomater	Sun-synchronous 830 Km high inclined at 98 7°	Sep 1976 (DMSP-1) June 1977(DMSP-2)May 1978 (DMSP-3) June 1979 (DMSP-4) all from Thor Burner (LV-2F)	DMSP-series (Defence Meteorological Satellite Programme) satellites are America's military weather satellites The operational network typically comprises of two satellites in polar orbit Data is made available to civilian users through NOAA
DSCS-II (Fig.19.32)	Spin	5	S-band transponders at 7 / 8 GHZ. Total of six channels	Geostationary	Launched in Pairs between Nov. 1971 and Oct 1982 All abroad Titan-III	DSCS (Defence Satellite Communications system) pronounced as 'Discus' is owned by US department of Defence and manufactured by TRW defence and space systems There are a total of 16 DSCS-II satellites.
DSCS-III	3-Axis	10	S-band and SHF transponders at 7/ 8 GHZ. Total	Geostationary	first DSCS-III-series satellite launched in Oct 1982 abroad titan 34 d.	Owned by US department of defence and manufactured by General Electric, DSCS-III is a replacement series for DSCS-II. The first two DSCS-III were considered Try-before-Buy proto types.

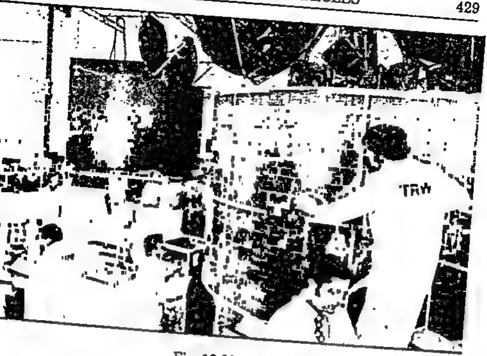


Fig. 19.32

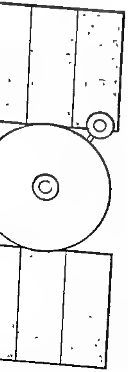


Fig 19.33

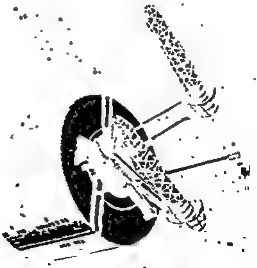


Fig. 19 34

Table 19.5. Military Satellites (Contd.)

Satellite	*Stabilisation*	*Design Life,yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
Fleetsat-com (Fig.19.33)	3--Axis	5	23 transponders workingat 244-400 MHZ. A fleet broadcast channel and nine relay transponders are dedicated to Navy, 12 narrow-band channels to USAF and one wideband channel to USAF and DOD.	Geostationary	Fleetsatcom-1 (Feb 1978), Fleetsatcom-2 (May 1979), Fleet satcom-3 (Jan 1980), Fleetsatcom-4 (Oct 1980), Fleetsatcom-5 (Aug 1981), and Fleetsatcom-6 (1985)	Fleetsatcom network owned by US department of defence and manufactured by TRW and Space systems provides global military coverage for the USAF and Navy. It provides UHF links among ships, submarines, Navy aircrafts and some land bases. It also provides a connection between USAF aircrafts and strategic air command centres.
LEASAT (Fig.19.34)	Spin	7	Total of 13 transponders-six for relay, one wideband, five narrowband and one fleet-broadcast	Near Geostationary. 35740 Km circular and incline at 3^0	First flight in 1984 (Space shuttle). Subsequent flights at six months intervals	The operational system comprises four satellites. LEASAT was a new concept in military comunications satellites in which the US navy leased a network from the manufacturer Hughes Aircraft.

Table 19.5. Military Satellites (Contd.)

Satellite	*Satbilis-ation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other features*
MILSTAR	-	-	Channels at EHF (a part of radio spectrum that recovers retatively fast from high altitude nuclear blasts)	Some crafts in geostationary and some in polar orbits	-	MILSTAR is a successor to programmes like fleetsatcom. It provides strategic and tactical communications for USAF, Army and Navy. MILSTAR is highly jam resistant and is designd for high survivability against electronic warfare and physical attack
NATO-III (Fig.19.35)	Spin	7	Three transponders in 7/8 GHZ	Geostationary	NATO-III A (April 1976) NATO-III B (Jan 1977) NATO-III C (Vov 1978) NATO-III D (Oct 1983) All abroad DELTA	Owned by NATO and manufactured by Ford aerospace, NATO-III series satellites provide rapid and secure communications among NATO members. The crafts are interoperable with DSCS
NATO-IV (Fig.19.36)	3-Axis	-	-	Geostationary	-	Contract for building two satellites of NATO-IVseries was awarded in 1987. It provides NATO members with secure military and diplomatic communications

Table 19.5. Military Satellites (Contd.)

Satellite	*Stabilis-ation*	*Design Life, yrs*	*Payload*	*Orbit*	*Launch*	*Other Features*
NAVSTAR	3-Axis	5 for first 11crafts and 7.5 for Block 2S	Three or four atomic clocks, Novstar-I to III each had three rubidium clocks. Navstar IV have these plus a caesium unit. Novstar addition (Possive sensors to monitor naclear blasts	Satellite are distributed around each of three orbits providing global coverage Each orbit is 20,200 Km high, circular and inclined at 63°.	Block-1S (Atlas E / F) Block 2S (Delta-2) Navstar-I(Feb 1978) Navstar-II (May 1978) Novstar-III(Oct 1978) Novstar-IV (Dec 1978) Navstar-V (Feb 1980), Navstar-VI (April 1980), Navstar-VII (Dec 1981) and Navstar-VIII (May 1983) Navstar-I (Block-2)(Feb 1989)	Navstar is a system for navigation via satellite Navstar was designed to aid weapon aiming by telling users their position with a higher accuracy than other navigation systems. The USAF intially planned 24 satellites but subseq-uently their number was reduced to 18. This would provide users with a position accuracy of 15 m anywhere in the world, atleast half of the time.
SKYNET-IV Fig. 19.37	3-Axis	5		Geostationary	Dec 1988 from ariane 4 (Skynet-IVA), 1989 from Titan-III (skynet-IVB) and 1990 from Ariane-4 (Skynet-IVC)	Skynet-IV is Britain's military communication satellite It provides links among ships, mobile terminals on land and control Centres. It has evolved from OTS/ECS technology.

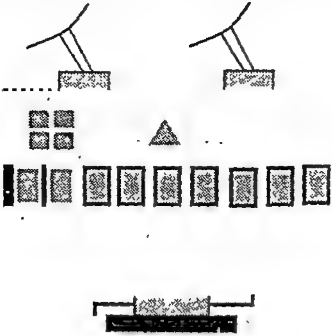


Fig. 19 35

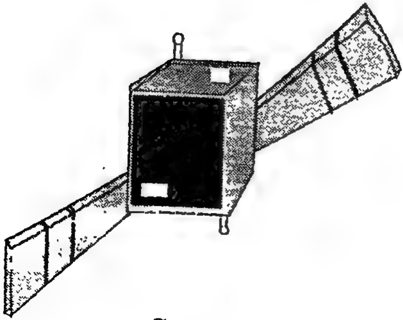


Fig. 19.36

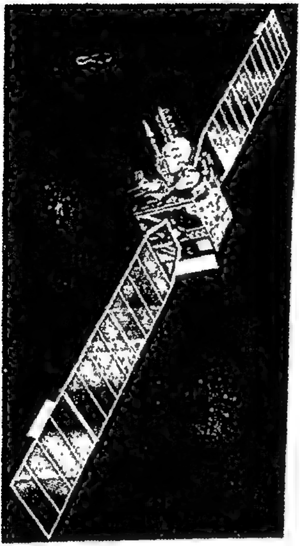


Fig. 19.37

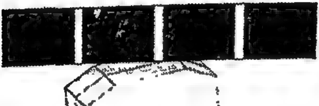


Fig. 19.38

Table 19.5. Military Satellites (Contd.)

Satellite	Stabilisation	Design Life, yrs	Payload	Orbit	Launch	Other features
NOVA	Gravity Gradient	5	-	Polar, 1075 Km high and Circular	May 1981	Nova is an improved version of US Navy's Transition satellite. It features on-board station-seeking and station-keeping which means that fewer updates are needed from ground stations.
TRANSIT NAVSAT [illegible]	Passive via Gravity Gradient	[illegible]	Beacons transmitting on 150 and 400 MHz	Polar 1075 Km high, circular)	-	TRANSIT is a series of navigation satellites operated by the US Navy and also used by civilians, particularly sailors. Position accuracy of about 100 m is possible in most of the world and intervals between fixes vary from 1/2 to 2 hrs depending upon the latitude. It is owned by U.S Navy (Department of Defence) and manufactured by RCA Astro Electronics

Table 19.6. Satellite Launch Vehicles

Mfr./Vehicle.	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairin*	*Total Length, m*	*Payload Capability*
American Bocket Company (USA) Aquilla-31	1st	3× H 1500	LOX + HTPB	2848 kN	75s	4 74 m long	30 78	1452 Kg to polar (Note 2)
	2nd	1× H1500(Note-1)	LOX+HTPB	1052KN	71s			–
	3rd	UTC Orbus 21S	Solid	985KN	148s			–
	4th	1× Amroc U-75	N_2O_4+ HTPB	41 KN	85s			–
Ariane Space (Europe) Ariane-44P	1st	4 × SEP Viking 5	UH25 + N_2O_4	2700KN	209s	short 8 6 long	54	3290 kg to GTO
		4 × SNIA-BPD (Note-8)	Solid	2600KN	42s	Long (Note 5) 9 6m long	55	4100 kg to sun syn (Note-7)
	2nd	1 × SEP Viking 4	UHF + N_2O_4	798KN	130s	Sylda (Note-9)	55	
	3rd	1 × SEP HM 7 B (Note-4)	LOX + LH	62KN	750s	Short SPELDA (Note-10) ASAP (Note-7)	57	

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr./Vehicle.	Stage	Engine	Propellants	Thrust	Burn Time	Payload Fairing	Total length, m	Payload Capability
Ariane Space (Europe) Ariane 42 P	1st	4 × SEP Viking 5	UH25 + N_2O_4	2700KN	200s	Short 8 6m long (Note-5)	54	2740 Kg to GTO
		2 × SNIA-BDP (Note-8)	Soild	1300KN	42s	long (Note-5) 9 6m long	55	2740 Kg to GTO
	2nd	1 × SEP Viking 4	UH25 + N_2O_4	798KN	130s	Sylda (Note-9)	-	-
	3rd	1 × SDEP HM 7 B	LH + LOX	62 KN	750s	ASAP (Note-7)	-	-
Ariane Space (Europe) Ariane 40P	1st	4 × SEP Viking 5	UH25 + N_2O_4	2700KN	154s	Short 8 6mlong	54	2020 kg to GTO (Note-7)
	2nd	1 × SEP Viking 4	UH25 + N_2O_4	798 KN	130s	Long (Note-5)	55	2700 kg to Sun syn (Note-7)
	3rd	1 × SEP HM 7 B (Note-4)	LH + LOX	62 KN	750s	9 6 m long ASAP (Note-7)	-	
Arianespace (EUROPE) Ariane-42 L	1st	4 × SEP Viking 5	UH25 + N_2O_4	2700KN	205s	Short 8 6m long	54	3320 kg to GTO
		2 × SEP Viking (Note-8)	UH25 + N_2O_2	1500 KN	132s	Long 9 6 m (Note-5)	55	4500 kg to Sun Sync

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr./ Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
	2nd	1 × SEP HM 7B	UH25 + N_2O_4	798 KN	130s	SDS (Notes 9,10)	55	,
	3rd	1 × SEP HM 7B (Note-4)	LH + LOX	62 KN	750s	-	-	,
Arianespace (EUROPE) Ariane 44 LP (Fig.19.39)	1st	4 × SEP Viking 5	UH25 + N_2O_4	2700KN	205s	Short 8.6 m long	54	4030 kg to GTO
		2 × SEP Viking 6 (Note-8)	UH25 + N_2O_4	1500 KN	143s	Long 9.6m (Note-5)	55	5300 kg to Sun sync.
		2 × SNIA-BPD (Note-8)	Solid	1300 KN	42s	Short SPELDA (Note-10,11)	57	,
	2nd	1 × SEP Viking 4	UH25 + N_2O_4	798 KN	130s	Long SPELDA (Note-12)	58	,
	3rd	1 × SEP HM 7B(Note-4)	LH + LOX	62 KN	750s	SDS (Notes 9,13)	55	,

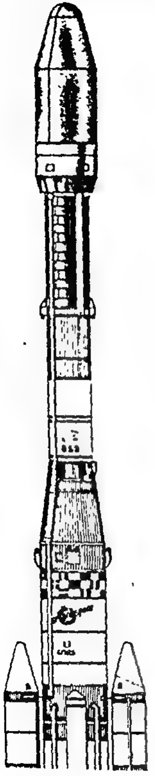


Fig 19 39

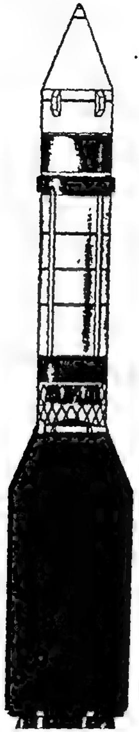


Fig 19.40

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehilce	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
Arianespace (Europe) Ariane 44 L	1st	4 × SEP Viking 6 (Note-8)	UH25 + N_2O_4	3000 KN	143s	Short 8.6m long	54	4460 kg to GTO
		4 × SEP Viking 5 (Note-8)	UH25 + N_2O_4	2700 KN	209s	Long 9.6m Long (Note-5)	55	6150 kg to Sun Sync
	2nd	1 × SEP Viking 4	UH25 + N_2O_4	798 KN	130s	Short SPELDA (Notes-10,11)	57	-
	3rd	1× SEP HM 7B (Note-4)	LH + LOX	62KN	750s	SDS (Notes-9,10)	55	-
Common-wealth of Independent States (CIS) Proton SL-12 (Fig.19 40)	1st	6 × RD 253 (Note-14)	N_2O_4 + UDMH	9438 KN	130s	7 6 m long	57 2	4600 kg to GTO (Note-16) and 2400 kg to GEO (Note-18)
	2nd	4 × RD – 0210	N_2O_4 + UDMH	2360 KN	300s			
	3rd	1 × RD 0210 + Verniers	N_2O_4 + UDMH	620 KN	250s	-	-	-

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length,m*	*Payload Capability*
	4th	Block DM (Note-15)	LOX + Kero	85 KN	600s			
Commonwealth of Independent States (CIS) Proton SL-13	Ist	6 × RD – 253 (Note-14)	N_2O_4 + UDMH	9438 KN	130s	7 6 m long	51.7 (Note17)	21000 kg to LEO (Note-18)
	2nd	4 × RD – 0110	N_2O_4 + UDMH	2360 KN	300s			
	3rd	1 × RD – 0210 + Verniers	N_2O_4 + UDMH	620 KN	250	-	-	
Commonwealth of Independent States (CIS), Vostok SL-3 (Fig 19.41)	Ist	1 × RD – 108 (Note-19)	LOX + KERO	745 KN	310s	7.7 m long	38.4	4730 kg to LEO 1840 kg to 650 km Sun Sync
		4 × RD – 107 (Note-20)	LOX + KERO	3284 KN	120s	-	-	-
	2nd	1 × RD – 448 (Note-21)	LOX + KERO	298 KN	440s	-	-	
Commonwealth of Independent States	Ist	1 × RD – 108 (Note-18)	LOX + Kero	745 KN	310s	10.14 m long	45 22	1150 kg to 920 km sun synchronous 7500 kg to LEO

Table 19.6. Satellite Launch Vehicles

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length,m*	*Payload Capability*
(CIS) Soyuz SL-4 (Fig.19.42)		4 × RD–107 (Note-19)	LOX + KERO	3284 KN	120s	Soyuz TM escape	49 52	•
	2nd	1 × RD–0110	LOX + KERO	298 KN	245s	Tower	-	
Commonwealth of Independent States(CIS) Molniya SL-6	1st	1 × RD–108 (Note-19)	LOX + KERO	745 KN	310s	-	45.2	1600 kg to 400 km × 40000 km orbit Molniya
		4 × RD–107 (Note-20)	LOX + KERO	3284 KN	120s	-		
	2nd	1 × RD–0110	LOX + KERO	298 KN	230s	-		900 kg to 400 km× 200,000 km orbit
	3rd	1× CI – 5400	LOX + KERO	67 KN	200s	-		
Commonwealth of Independent States (CIS) Cosmos SL-8	1st	2 × RD–216	N_2O_4 + UDMH	1470 KN	170s	-	32	1700kg to 180 Km LEO, 100 kg to 800 km × 1500 km orbit
(Fig 19 43)	2nd	1 × (with Verniers)	N_2O_4 + UDMH	157 KN	375s	-	-	

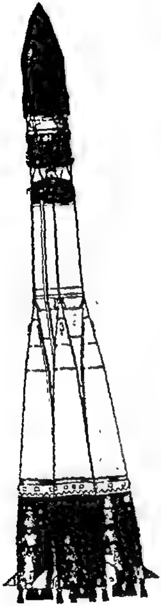


Fig 19.41

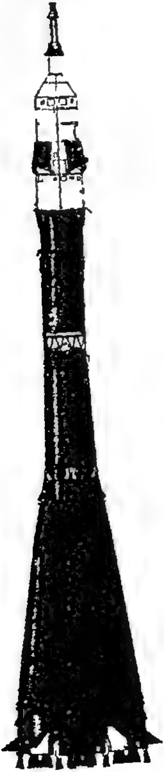


Fig 19.42

Table 19.6. Satellite Launch Vehicles

Launch Vehicle	Stage	Engine	Propellants	Thrust	Burn Time	Payload Fairing	Total Length	Payload Capability
[illegible]		4 × RD-	LOX + KERO	1284 KN	120	[illegible]		

Fig. 1

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length, m*	*Payload Capability*
Commonwealth of Independent States (CIS)	Ist	1 × + 4 Verniers	N_2O_4 + UDMH	2747 KN	120s	11.3 m long	39.27 m	5500 kg to 65°LEO
Tsyklon SL-14 (Fig.19.44)	2nd	1 × + 4 Verniers	N_2O_4 + UDMH	1012 KN	160s			
	3rd	1	N_2O_4 + UDMH	78 KN	118s			
Commonwealth of Independent States (CIS)	Ist	1 × + 4 Verniers	N_2O_4 + UDMH	2747 KN	120s	-	-	3000 kg to 65°LEO
Tsyklon SL-11	2nd	RD-219	HNO_3 + UDMH	883 KN	125s			
Commonwealth of Independent States (CIS)	Ist	1 × RD – 171	LOX + KERO	7259 KN	144s	13 65 m long	61 4	13740 kg to LEO
Zenit SL-16	2nd	1 × RD – 120 Verniers	LOX + KERO	912 KN	300s	11 15 m long	57	11380 kg to Sun synchronous

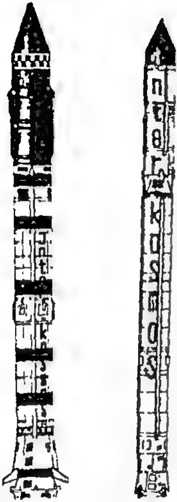


Fig 19 43

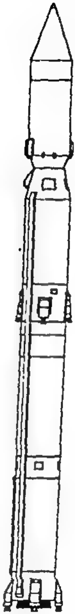


Fig 19 44

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length, m*	*Payload Capability*
Commonwealth of Independent States (CIS)	1st	1 × +4 Verniers	N_2O_4 + UDMH	2747 KN	120s	11.3 m long	39 27 m	5500 kg to 65°LEO
Tsyklon SL-14 (Fig 19 44)	2nd	1 × +4 Verniers	N_2O_4 + UDMH	1012 KN	160s			
	3rd	1	N_2O_4 + UDMH	78 KN	118s			
Commonwealth of Independent States (CIS)	1st	1 × +4 Verniers	N_2O_4 + UDMH	2747 KN	120s	-	-	3000 kg to 65°LEO
Tsyklon SL-11	2nd	RD-219	HNO_3 + UDMH	883 KN	125s			
Commonwealth of Independent States (CIS)	1st	1 × RD – 171	LOX + KERO	7259 KN	144s	13 65 m long	61 4	13740 kg to LEO
Zenit SL-16	2nd	1 × RD – 120 Verniers	LOX + KERO	912 KN	300s	11 15 m long	57	11380 kg to Sun synchronous

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
Commonwealth of Independent States (CIS), Energia SL-17	Ist	4 × RD – 0120 (Note-19)	LH + LOX	5804 KN	450s	42 m long (Note-22)	58 7	105,000 kg to LEO 85000 kg to sun sync
		4 × RD – 170 (Note-20)	LOX + KERO	29028 KN	140s		58 7	
	2nd	1 (Note-22)	LOX + KERO	85 KN		Buran (Note 23)- 8 99 m long	58 7	
E Prime Aerospace (USA), Eagle S-2	Ist	1 × Thiokol ESM 9 (Note -28)	Solid	2234 KN	56s		32 91	4535 kg to LEO
	2nd	1 × Thiokol ESM 9	Solid	2234 KN	56s			4989 kg to LEO (Note-26)
	3rd	1 × Thiokol ESM 3	Solid	383 KN	140s			4151 kg to GEO (Note 25 and 27)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
EER Systems / Space Services Inc. (U.S.A.) Conestoga 1620 (Note-28)	1st (Notes-29-31)	2 × Thiokol Castor 4 A	Solid	884 KN	54s	7.01 m long	15.82	816 kg to 480 km LEO (Note-32)
		2 × Thiokol Castor 4B (Note-29)	Solid	735 KN	64s		-	
	2nd (Notes-29,30)	2 × Thiokol castor 4B	Solid	735 KN	64s	7.01 m long	15.82	
		1 × Thiokol castor 4B	Solid	368 KN	64s	-	-	-
	3rd	1 × Thiokol castor 4B	Solid	368 KN	64s	-	-	-
	4th	1 × Thiokol Star 48 V	Solid	70 KN	85s	-		-
European space Agency (ESA)	1st	1 × SEP HM60 Vulcain	LH + LOX	1120 KN	590s	Short 12.7 m long	45.7	6900 kg to GTO (Single)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length,m*	*Payload Capability*
Ariane-5 (Fig.19 45)		2 × BPD / SNPE (Note-33)	Soild	11800 KN	123s	Long 19.2 m long	51 4	5950 kg to GTO (Dual)
	2nd	1 × MBB L9 (Note 34,35)	N_2O_4 + MMH	28 KN	1150s	Short, SPELTRA (Note-36)	55 9	5115 kg to GTO (Triple) (Note-37)
						Long SPELTRA (Note-36)	52 2	1800 kg to 550 km28°
						SPILMA (Note-37)	52 2	10000 kg to 800 km Sun Sync.
						HERMES (Note-39)	51 3	22600 kg to LEO Hermes (Note-38)
General Dynamics Commercial Launch	Ist	1 × Rocketdyne MA-5 (Note-39)	LOX + RP-1	195 KN	-	Medium 10 36 m long	42m	5900 kg to 85 km 28° LEO (Note-41)

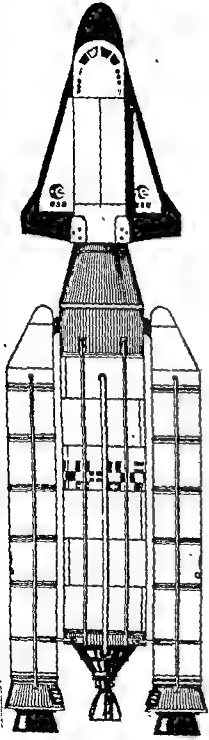


Fig 19.45

Fig. 19.46

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thurst*	*Burn Time*	*Payload Fairing*	*Total Length,m*	*Payload Capability*
Services (U.S.A.) Atlas-1		1 Sustainer			288s	-	-	2340 kg to GTO (Note-41)
		2 Booster Engines			169s	Long 12 22 m long	43.9m	
	2nd	2 × P & W RL10 A-3-3A (Note-40)	LH /LOX	147KN	473s	-	-	2250 kg to GTO (Notes 42, 48)
General Dynamics Commerical Launch Services (U.S.A) Atas-2/MLV-2 (Note-43) (Fig.19.46)	1st	Rocketdyne MA-5 (Note-39)	LOX + RP-1	2109 KN	-	Medium 10 36m (Note44)	45 6	6780 kg to 185 km 28° LEO (Note-41)
		2 Booster Engines			169s	Long		28° LEO (Note-41)
		1 Sustainer			277s	Long 12 22 m long	47 6	6580 kg to 185 km 28° LEO (Note42)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
	2nd	2 × P & W RL10A-3-3-A (Note-40)	LH + LOX	147 KN	473s	-		2770 kg to GTO (Note-41)
								2580 kg to GTO (Note 42, 46)
General Dynamics Commercial Launch Services (U.S.A.) Atlas 2 A	Ist	1 × Rocketdyne MS-5A	LOX + RP-1	2109 KN		Medium 10.36m long	45.6	7120 kg to 185 km
		2 booster engines			169s	Long	47.6	28° LEO (Note-41)
		1 Sustainer			277s	Long 12.22m		6920 kg to 185 km 28E° (Note-42)
	2nd	2 × P &W RL-10-4 (Note-40,47)	LH + LOX	185 KN	473s			2900 kg to GTO (Note-41)
								2810 lg to GTO(Note-42)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	Stage	Engine	Propellants	Thrust	Burn Time	Payload Fairing	Total Length, m	Payload Capability
General Dynamics Commercial Launch Services (U.S.A.) Atlas 2AS	1st	1 × Rocket dyne MA-5A	LOX + RP-1	2109 KN				
		2 booster engines			169s	Medium 10.3 m long	45 6	8600 Kg to 185 km 28° LEO (Note-42)
		1 Sustainer			277s	Long 12.22m long	47 6	3630 kg to GTO (Note-41)
		4 × Thiokol Castor 4A	Solid	173 KN	56s			
	2nd	2 × P&W RL-10-4 (Note 40,46)	LH + LOX	185 KN	473S			3490 kg to GTO (Note-42)
General Dynamics US Airforce Atlas E/SVS (Note-49)		1 × Rocketdyne MA-3 (Note-50)	LOX + RP-1	1950 KN		7 62 m long	28	1814 kg to Sun Sync with Block-1 SVS

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
		2 boosters			172s			2041 kg to Sun Sync, with Block-2 SVS
		1 Sustainer			288s			
	2nd	Block 1 or 2 stage vehicles solid system (SVS)	Solid					
Greatwall Industry Corporation (China) Long March 2 CZ-2	1st	4 × YF-20	N_2O_4 + UDMH	2785 KN	132s	Medium 7.12m long	35 1	750 kg to 900 km Sun Sync 1200 kg to 200 km × 900 km 2000 kg to 400 km× 185 km

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Enigne*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length,m*	*Payload Capability*
	2nd	1 × YF-22 + Verniers	N_2O_4 + UDMH	762 KN	110s	Long 8 7 m long	38.4	1000 kg to GTO (Note-51) Piggiback Payloads LEO
Greatwall Industry Corporation (China) Longmarch 2E, CZ-2E (Fig 19 47)	1st	4 × YF – 20 (Note-59)	N_2O_4 + UDMH	2942 KN	158s	Medium 7 12 m long	35.1	9200 kg to 200 km 28° LEO(Note-53)
		4 × YF – 20 (Note-52)	N_2O_4 + UDMH	2942 KN	125s	Long 8.7m long	38 4	7200 kg to 400 km 28° LEO (Note 53)
	2nd	1 × YF-25/23	N_2O_4 + UDMH	832 KN	300s			2494 kg to GTO (Notes-54,55) 3370 kg to GTO (Notes-54,56)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length,m*	*Payload Capability*
								4500 kg to GTO (Notes-54,57)
Great wall Industry corporation (China) Longmarch 3 A, CZ-3A (Fig.19.48)	Ist	4 × YF – 20 (Note-59)	N_2O_4 + UDMH	2942 KN	160s	2 9m long	41 89	4000 kg to LEO
	2nd	1 × YF-25	N_2O_4 + UDMH	766 KN	110s	8 4 m long	47.39	1000 kg to 1000 km orbit
	3rd	2 × YF-75 (Note-58)	N_2O_4 + UDMH	98 KN	410s	-	-	1500 kg to Sun Sync.
Greatwall Industry Corporation Long March, 4, CZ-4 (Fig 19 49)	Ist	4 × YF – 20 (Note-59)	N_2O_4 + UDMH	2942 KN	160s	2 9 m long	41 89	4000 kg to LEO
	2nd	1 × YF – 25	N_2O_4 + UDMH	766 KN	110s	8 4 m long	47.39	1000 kg to 1000 km orbit
	3rd	2 × YF – 40 (Note-58)	N_2O_4 + UDMH	98 KN	410s			1500 kg to Sun Sync
Indian Space Research Organisation ISRO)	Ist	1 (Note-60)	Solid	503 KN	46s	-	23.5	150 kg to 400 km 45° Orbit

Fig. 19.48

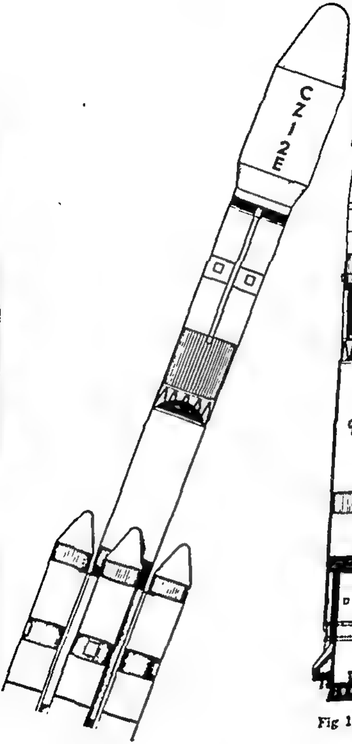


Fig. 19 47

Fig 19 49

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length,m*	*Payload Capability*
(INDIA) Augmented Satellite launch Vehicle (ASLV) (Fig.19.50)		2 (Note-61)	Solid	880 KN	50s	-		
	2nd	1	Solid	218 KN	36s	-		
	3rd	1	Solid	64 KN	44s	-		
	4th	1	Solid	26 KN	32s	-		
Indian Space Research Organisation ISRO (INDIA) Polar Satellite Launch Vehicle (PSLV)	1st	1	Solid	4600 KN	94s	8 3 m long	44.2	1000 kg to 904 km Sun Sync.
		6 (Notes 61,62)	Solid	2460 KN	54s			
	2nd	1 × Vikas	N_2O_4 + UDMH	735 KN	150s			3000 kg to LEO
((Fig.19.51)	3rd	1	Solid	386 KN	74s			450 kg GTO
	4th	2	N_2O_4 + UDMH	14 KN	425s			
Institute of Space and Astronautical Sciences, ISAS (Japan) MS3 II	1st	1 × Nissan	Solid	1275 KN	94s	6 86 m long	27.78	770 kg to 250 km LEO

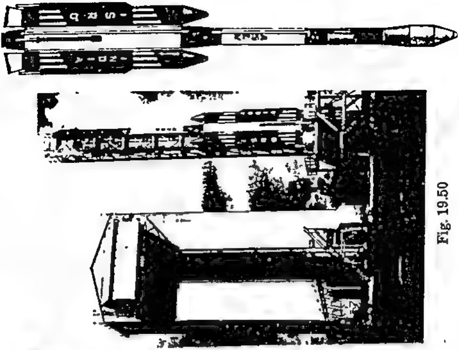


Fig. 19.50

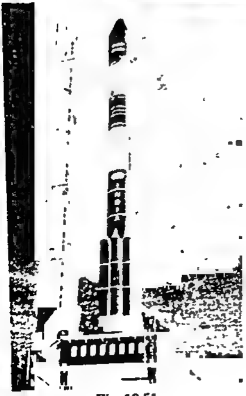


Fig. 19 51

Fig. 19 52

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length,m*	*Payload Capability*
Indian Space Research Organisation ISRO (INDIA)		2 × Nissan (Note-63)	Solid	327 KN	54s			460 kg to 500 km LEO
	2nd	1 × Nissan	Solid	524 KN	73s			
	3rd	1 × Nissan	Solid	132 KN	87s			
	4th	1 × Nissan	Solid	32KN	44s			
Geosynchronous Satellite launch Vehicles(GSLV)	Under Development : Five Launches Planned -1995-96 (First), 1996-97 (Second), 1997-98 (Third), 1999-2000 (Fourth and Fifth)							2500 kg toGTO
Institute of Space and Astronautical Sciences, ISAS (Japan) M5	Ist	1 × M14	Solid	43000 KN	45s	5m long (approx)	31.2	2000 kg to LEO
	2nd	1 × M24	Solid	1400 KN	63s			
	3rd	1 × M34	Solid	300 KN	101s			

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	Stage	Engine	Propellants	Thrust	Burn Time	Payload Fairing	Total Length, m	Payload Capability
Instiute de Actividades Espaciais (Brazil) Veiculo Lancador de Satelites (VLS)	Ist	1 × S43 TM	Solid	303 KN	62s	1 18 m long	18.8	115 kg to 750 km
		4 × S43 (Note 64)	Solid	1172 KN	62s			160 kg to 650 km (Note-65)
	2nd	1 × S40 TM	Solid	191 KN	58s			
	3rd	1 × S44	Solid	31 KN	73s			
International Microspace (U.S.A.) Orbilat Express	Ist	Thiokol Castor 4B	Solid	359 KN	64s	2 15m	21 33	180 kg LEO
	2nd	Thiokol Castor1	Solid	240 KN	40s			
	3rd	Bristol Aerospace Nihka	Solid	51 KN	18s			
	4th	Thiokol Star 20	Solid	27 KN	30s			
International Microspace (U.S.A.)	Ist	5 × SS – 1 Scud	Liquid	696 KN	-		24.4	150 kg to LEO
IRAQ (Tamouz)	2nd	1 × SS – 1 Scud	Liquid	137 KN	-	-		

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehcle.	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length, m*	*Payload Capability*
Martin Marietta Space launch systems (U.S.A.) Titan 2G (Note-67)	Ist	2 × Aerojet LR-87-AJ 5	N_2O_4 + A 50	1913 KN	170s	-	37 5	2180 kg to 185 km polar
	2nd	1 × Aerojel LR9-AJ5	N_2O_4 + A 50	445 KN	183s			
Martin Marietta Space launch Systems (U S A) Titan 4 (NUS)	Ist	2 × Aerojet - LR-87-AJ 5	N_2O_4 + A 50	2434 KN	186s	17.06 m long	53.99	3082 kg 560 km Sun Sync (Note-68) 17770 kg LEO
		2 UTC SRM (Note-68)	Solid	14234 KN	127s			
	2nd	2 Aerojet-LR91 AJ-11A	N_2O_4 + A 50	467 KN	240s			
Martin Marietta Space Launch Systems (U S.A.) Titan 4-(IUS)	Ist	2 Aerojet LR87-AJ 11-A	N_2O_4 + A 50	2434 KN	186S	17.06 long	53.99	2361 kg to GEO
		2 UTC SRM (Note-68)	Solid	14234 KN	127s			
	2nd	2 Aerojet-LR91 AJ-11A	N_2O_4 + A 50	467 KN	240s			

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload*	*Total Langth,m*	*Payload Capability*
	3rd	1 × Boeing IUS Ist 2nd	solid	203 KN	152s			
		2nd	Solid	82 KN	289s			
Martin Marietta Space launch Systems (U S.A) Titan 4-Centaur	Ist (Note-69)	2 × Aerojet LR 87 AJ-11A	N_2O_4 + A 50	2434 KN	186s	26.23 m long	63 14	4545 kg tc GEO
	2nd	2 × AerojetL R91 AJ-11A	N_2O_4 + A 50	467 KN	240s			
	3rd	2 × P & W RL-10 3-3-A (Note-71)	LH + LOX	147 KN	617s			
Martin Marietta Space Launch Systems (U S.A.) Titan 4-IUS (SRMU) (Note-72)	Ist (Note-69)	2 × Aerojet LR87 AJ-11A	N_2O_4 + A 50	2434 KN	186s	17.06m long	53 99	21900 kg to GEO
		2 × Hercules SRMU (Note-70)	Solid	15124 KN	145s			
.	2nd	2 × Aerijet LR 91 AJ-11A	N_2O_4 + A 50	467 KN	240s			

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
	3rd		Liquid	-	-	-		
International Microspace (U S A.) ISRAEL (Shavil)	1st	1	Solid	-	-	-	13 (Note-66)	150 kg to 250 km by 1150 km orbit
	2nd	1	Solid	-				
	3rd	1	Solid					
International Microspace (U S.A.) LTV USA (Scout G-1) (Fig 19.52)	1st	1 × UTC Algol 3A	Solid	465 KN	62s			
	2nd	1 × Thiokol Castor 2A	Solid	268 KN	38s	-	22.9	205 kg to 555 km
	3rd	1 × Thiokol Antares 3A	Solid	81 KN	45s			37° orbit (Note-66)
	4th	1 × Thiokol Altair 2A	Solid	26 KN	29s			165 kg to 555 km Sun Sync (Note-67)
								220 kg to 555 km equatorial orbit (Note-68)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length, m*	*Payload Capability*
	3rd	1 × Boeing IUS Ist	Solid	203 KN	152s			
	2nd		Solid	82 KN	289s			
Martin Marietta Space Launch Systems (U S A.) Titan 4-NUS (SRMU) (Note-72)	Ist (Note-69)	2 × Aerojet LR 87 AJ-11A	N_2O_4 + A 50	2434 KN	186s	26.3 m long	63.14	5773 lg to GEO
		2 × Hercules SRMU (Note-70)	Solid	15124 KN	145s			
	2nd	2 × Aerojet LR91 AJ-11A	N_2O_4 + A 50	467 KN	240s			
Martin Marieta Commercial Titan (U S A.) Commercial Titan	Ist (Note-69)	2 × Aerojet LR 87-AJ-11	N_2O_4 + A 50	2438 KN	160s	10.4 m long	44.06	14742 kg to LEO
		2 × UTC (Note-70)	Solid	12454 KN	114s			1279 kg to GTO (Note-73)
	2nd	2 × Aerojet LR 91 AJ-11A	N_2O_4 + A 50	467 KN	225s			4944 kg to GTO (Note-74)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	Stage	Engine	Propellants	Thrust	Burn Time	Payload Fairing	Total Length, m	Payload Capablity
								49990 kg to GTO (Note-75)
[illegible]	[illegible]	[illegible]	N_2O_4 + A 50	2434 KN	186s	2 6.3 m long	63 14	5773 kg to GTO
		[illegible]	[illegible]	15124 KN	145s			
	[illegible]	[illegible]	[illegible]	[illegible] KN	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible] KN	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible] KN	[illegible]	[illegible] m long	[illegible]	3983 kg to [illegible] km
	[illegible]	[illegible]	[illegible]	[illegible] KN	[illegible]	[illegible] m long	[illegible]	[illegible] (Note-[illegible])
		[illegible] Star 48B						

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. /Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
	2nd	1 × Aerojet AJ-10 / 118 K (Note-79)	N_2O_4 + A 50	43 KN	440s			2413 kg to 833 km Sun Sync (Note-81)
Mcdonnlel Dougles U S.A. Interim Delta-26925	Ist (Note-77)	1 × Rocketdyne RS-27	LOX + RP – 1	920 KN	265s	8 .5 m long	37.8	1447 kg to GTO (Note-80)
	Nute-78	9 × Thiokol Castor-A4	Solid	3829 KN	56s	9.7 m long	39	
	2nd	1 × Aerojet AJ10-118K (Note-79)	N_2O_4 + A 50	43 KN	440s			
	3rd	1 × MDC PAMD / Star 48 B	Solid	67 KN	88s			839 kg to GPS (Note-80)
Mcdonnel Douglas (U.S.A.) Delta-2,7920	Ist	1 × Rocketdyne RS-27 (Note-82)	LOX + RP-1	894 KN	267s	8 5 m long	37.8	5039 kg to LEO (Note-80)

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
		9 × Hercules GEM (Note-78)	Solid	3957 KN	56s	9.7 m long	39	839 kg to GPS (Note-80)
	2nd	1 × Aerojet AJ10-118K (Note-79)	N_2O_4 + A 50	43 KN	440s			
Mcdonnel Douglas U S A. Delta-2,7925	1st	1× Rocketdyne RS-27 (Note-82)	LOX + RP-1	895 KN	265s	8.5 m long	37.8	1819 kg GTO (Note-80)
		9 × Hercules GEM (Note-78)	Solid	3957 KN	64s	9.7 m long	39	1134 kg to GPS (Note-80)
	2nd	1 × Aerojet Aj-10–118k (Note-79)	N_2O_4 + A 50	43 KN	413s			
	3rd	1 × MCDPAMD Star 48B	Solid	67KN	88s			

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr./Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total Length, m*	*Payload Capability*
NASDA / ISAS (Japan) J1	1st	1 × Nissan (Note-83)	Solid	1569 KN	95s	3 85 m long	32.9	1000 kg to LEO
	2nd	1 × Nissan M 23 *(Note-84)*	Solid	524 KN	73s			200 kg to GTO
	3rd	1 × Nissan M 3B (Note-84)	Solid	132 KN	87s			
NASA (U.S.A.)	1st	3 × Rocket dyne SSME (Note-86)	LH + LOX (Note-87)	5262 KN	520s	18.28 m long (Note-90)	56.14	24990 kg to 28° LEO
Space Shuttle Orbiters :		2 × Thiokol SRM	PATP (Note-88)	39360 KN	120s		37.24 (Note-91)	
Columbia, Atlantis, Discovery, Endeavour (Fig 19.53)	2nd	3 × OMS Aerojet (Note-86)	N_2O_4 + UDMH	80 KN	15h			18600 kg to 57° LEO
NASA (U.S.A.) Space Shuttle ARSM (Note-92)	1st	2 Rocket dyne SSME (Note-93)	LH + LOX (Note-87)	5262 KN	5D20s	18 28 m long (Note-90)	56.14	29483 kg to 28° LEO

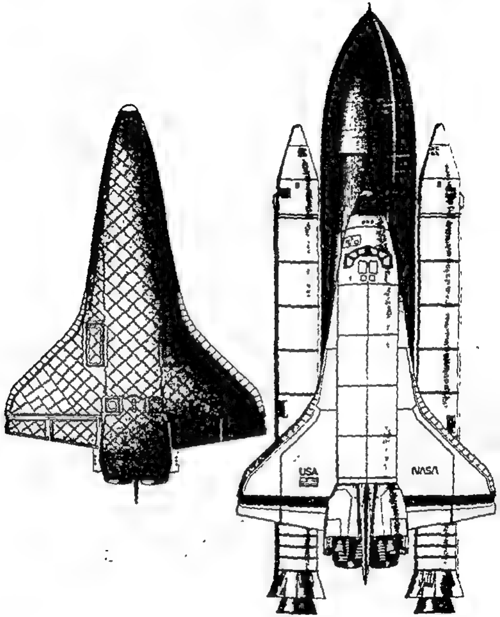


Fig. 19.53

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length, m*	*Payload Capability*
		2 × Lockheed Aerojet ARSM	HTPB (Notes 85,94)	31320 KN	130s		3.724 (Note-91)	
	2nd	3 × OMS Aerojet (Note-89)	N_2O_4 + UDMH	80 KN	15h			
National Space Devlopment Agency Rocket Systems Corporation (Japan) H2 (Fig 19.54)	1st	1 × Mitsubishi LE-7	LH + LOX	912 KN	348s	12 m long	49	9400 kg to LEO
		2 × Nissan SRB (Note-95)	Solid	3138 KN	95s			3800 kg to LEO
	2nd	1 × Mitsubishi LE5 A (Note-96)	LH + LOX	122 KN	610s			2000 kg to GEO 4500 kg atao Sun Sync.

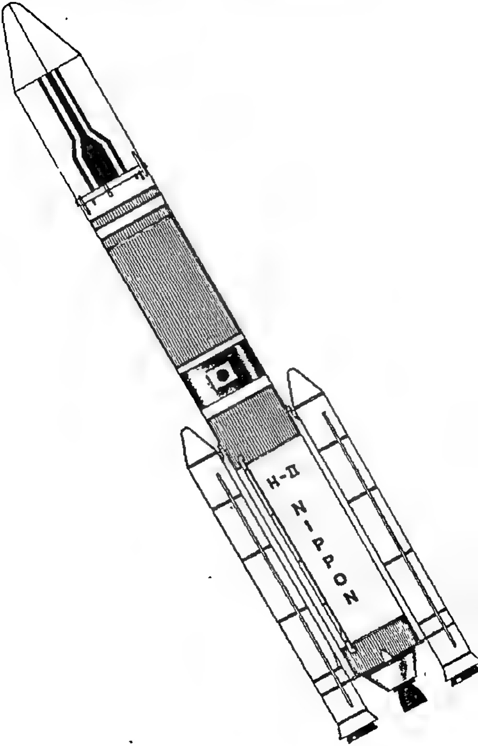


Fig. 19.54

Table 19.6. Satellite Launch Vehicles (Contd.)

Mfr. / Vehicle	*Stage*	*Engine*	*Propellants*	*Thrust*	*Burn Time*	*Payload Fairing*	*Total length, m*	*Payload Capability*
Orbital Sciences Corporation OSC (U.S.A.) Pegasus (Note-97)	Ist	1 × Hercules	Solid	487 KN	73s (Note-98)		15.51	260 kg to polar
	2nd	1 × Hercules	Solid	123 KN	72s			350 kg to equatorial, 185 kmorbits (Notes 99,100)
	3rd	1 × Hercules	Solid	35 KN	65s			
Orbital Sciences Corporation, OSC (U S A.) Taurus / SSLV	Ist	1 × Thiokol (MX)	Solid	2200 KN	55s		27.51	1360 kg to LEO
	2nd	1 × Hercules	Solid	487 KN	73s			330 kg to GTO
	3rd	1 × Hercules	Solid	123 KN	72s			930 kg to Polar
	4th	1 × Hercules	Solid	35 KN	65s			930 kg to Polar

Notes (Table-6)

1.Core stage ignites at 20,000 2. Acquilla 21 with 2 HI500s-, 134 kg to LEO 3. Target date depends on final funds 4. New third stage H10 + intro Apr 92 5. 11.1 m Extra long fairing on request 6. Single payload only 7. Can carry microsats 8. Boosters 9. Used for dual launch, with long fairing 10. Used for dual launch with short fairing 11. Used with long or short fairing 12 Used with short fairing 13. ultra-short spelda for smaller payload flying with major satellite 14. Six UDMH modules around N_2 O_4 core 15. Restart capability / 2 hours 16. not used LEO 17. Depends on payload 18. Uprated Proton planned : 4500 kg to GEO and 23500 kg to LEO 19. Core called second stage 20. Strap-ons called first stage 21. Maximum 22. Piggiback 23. Piggiback +OMS engines 24 Ignites at 61 m after steam ejection canister launch 25. With aerojet USTM Motor 26. Wth post boast Motor 27. Variants of motor cluster combinations available .28.Comet configuration 29. Strap-ons 30. Core stage 31. Four strap-ons burn as first stage , two strap-ons and core stage ignite at T+60-61s 32. Variants of motor cluster combinations available 33. Boosters 34. Automatic launches / not Hermes 35. Restart capability 36. For dual launches 37. For triple launches with SPELTRA /not under development 38. Fully loaded, crewed needs MK2 Vulcain /not under development 39. + Verniers. 40. Restart capability 41. With medium fairing 42. With long fairing 43 Stretched Atlas and Centaur 44.MLV2 use medium only 45 MLV2 46. 8 percent performance increase optional with Block-1 enhancement package 47. Uprated Centaur 48. Boosters 49. Only Atlas flying 50 . + two verniers 51. China CPK solid propellant stage avilaible late 1992 52. Strap-ons 53. Jiuquan 54. Xichang 55. With PAM class perigee motor 56. China EPKM upper stage available 1993 57. China HO upper stage from CZ-3 58. Restart capability 59. Uprated CZ-3A available 60. Ignites at T+49.5s 61. Strap-ons 62. Four strap-ons 63. Strap-ons 64. Strap ons 65. With small motor 66. Approx 67. Refurbished ICBM 68. With star-37 Kick stage 69. Ignites at (T+116)s 70.Strap-ons 71. Restart capability 72. Under threat of cancellation 73. PAM D 74. IUS 75. TOS 76. Intelsat-6 stranded, no fault of Titan 77. Uprated Delta 3920 78. 6 ignite at launch, 3 at (T+62)s 79. Restart 80. Canaveral 81. Vendenberg 82. Improved expansion ratio 83. H2SRB 84. M3S II stages 85. H1 pad 86. Throttled 65 percent -104 percent

rated power 87. Fed from external tank 88. Strap-ons 89. Fired in pairs in 2s bursts. For final orbit and retro -fire. 90. Payload bay 91. Orbiter 92. NASA may cancel ARSM Sept 92 93 . 104 percent continuous 94. Throttleable 95. Strap-ons 96. Restart capability 97. Winged booster, air launched by B-52/Tristar, Mach 0.8. 12000m 98. Incorporates 3rd stage 99. Optional 4th stage hydrazine HAPS engine provides 40kg+ to polar 100. East coast launch for equatorial.

TWENTY

Solved Problems

Problem - 1 :

Refer to Fig. 20.1. The basis of a satellite orbitting around earth is the centripetal force (F_1) due to earth's gravitation acting towards the center of the earth balancing the centrifugal force (F_2) acting away from the center. Calculate the centrifugal force for a satellite of mass 100 kg orbitting with a velocity of 8 km/s at a height of 200 km above the surface of earth. Assume mean radius of earth to be 6370 km.

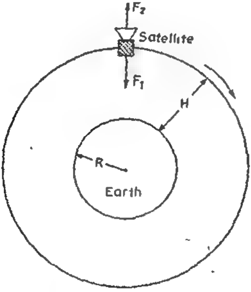


Fig. 20.1

Solution :

$$\text{Centripetal force} = \frac{mV^2}{(R+H)}$$

where m = mass of satellite

V = orbital velocity

R = mean radius of earth

H = height of satellite above surface of earth

The centripetal force balances the centrifugal force.

Therefore, Centrifugal force $= \dfrac{mV^2}{(R+H)}$

$$= \frac{100 \times (8000)^2}{(6370+200)\times 10^3}$$

$$= \frac{64 \times 10^8}{6570 \times 10^3}$$

$= 974$ Newtons

Problem - 2 :

Determine the orbital velocity of a satellite moving in a circular orbit at a height of 150 km above the surface of earth given that gravitation constant, $G = 6.67 \times 10^{-11}$ N–m²/ kg², mass of earth, $M = 5.98 \times 10^{24}$ kg, radius of earth, Re = 6370 km.

Solution :

The orbital velocity (V) is given by

$$V = \sqrt{\mu/(R+H)}$$

where $\mu = GM = 6.67 \times 10^{-11} \times 5.98 \times 10^{24}$

$= 39.8 \times 10^{13}\ \text{Nm}^2/\text{kg}$

$R = 6370$ Km

$H = 150$ Km

$$V = \sqrt{39.8 \times 10^{13}/(6370+150)\times 10^3}$$

$= 7.813$ Km/S

Problem - 3 :

A satellite in an elliptical orbit has an apogee of 30,000 km and a perigee of 1000 km. Determine the semi-major axis of the elliptical orbit.

Solution :

Semi-major axis $= \dfrac{\text{Apogee} + \text{Perigee}}{2}$

$$= \frac{30000 + 1000}{2}$$

$$= 15500 \text{ Km}$$

Fig. 20.2 illustrates the point further.

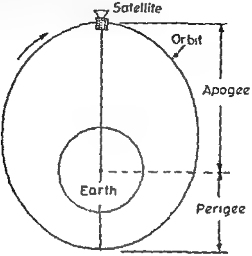


Fig. 20.2

Problem - 4 :

A satellite moving in an elliptical eccentric orbit has the semi-major axis of the orbit equal to 16000 km (Fig. 20.3). If the difference between the apogee and the perigee is 30000 km, determine the orbit eccentricity.

Solution :

Apogee $= a(1+e)$

Perigee $= a(1-e)$

where a = semi-major axis of the ellipse

e = orbit eccentricity

Apogee − Perigee $= a(1+e) - a(1-e)$

$= 2ae$

or Eccentricity, $e = \dfrac{\text{Apogee} - \text{Perigee}}{2a}$

$$= \frac{30000}{2 \times 16000}$$

$$= \frac{30000}{3200}$$

$$= 0.93.$$

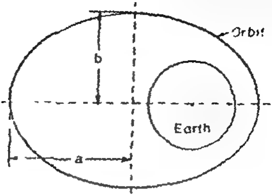


Fig 20.3

Problem - 5 :

The farthest and the closest points in a satellite's elliptical eccentric orbit from earth's surface are 30,000 km and 200 km respectively. Determine the apogee, the perigee and the orbit eccentricity. Assume radius of earth to be 6370 km.

Solution :

Apogee $= 30000 + 6370 = 36370$ km

Perigee $= 200 + 6370 = 6570$ km

$$\text{Eccentricity} = \frac{\text{Apogee} - \text{Perigee}}{2a}$$

where a = semi-major axis of the elliptical orbit

Also, $$a = \frac{\text{Apogee} + \text{Perigee}}{2}$$

or $$2a = \text{Apogee} + \text{Perigee}$$

$$\text{Therefore, orbit eccentricity} = \frac{\text{Apogee} - \text{Perigee}}{\text{Apogee} + \text{Perigee}}$$

$$= \frac{36370 - 6570}{36370 + 6570}$$

$$= \frac{29800}{42940} = 0.693.$$

Problem - 6 :

Refer to Fig. 20.4 showing a satellite moving in an elliptical, eccentric orbit. Determine the apogee and perigee distances if the orbit eccentricity is 0.5.

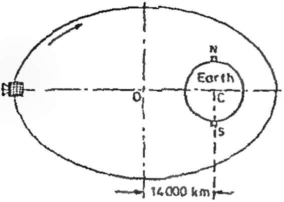


Fig 2.4

Solution :

The distance from center of ellipse (o) to the centre of earth (c) is given by $(a \times e)$ where (a) is the semi-major axis and (e) is the eccentricity.

Therefore, $a \times e = 14000$

$$a = \frac{14000}{0.5} = 28000 \text{ Km}$$

Now apogee $= a(1+e)$

$= 28000\ (1+0.5)$

$= 42000$ Km

Perigee $= a\ (1-e)$

$= 28000\ (1-0.5)$

$= 28000 \times 0.5$

$= 14000$ km

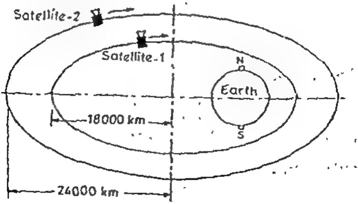


Fig. 20.5

Problem - 7 :

Satellite - 1 in an elliptical orbit has the orbit semi-major axis equal to 18000 km and Satellite - 2 in an elliptical orbit has semi-major axis equal to 24000 km (Fig. 20.5). Determine the relationship between their orbital periods.

Solution :

The orbital time period (T) is given by

$$T = 2\pi \sqrt{a^3/\mu}$$

where $\mu = GM$

G = Earth's gravitation constant

M = mass of earth.

a = semimajor axis of ellipse

If (a_1) and (a_2) are the values of the semi-major axis of the elliptical orbits of the satellites 1 and 2, (T_1) and (T_2) are the corresponding orbital periods, then

$$T_1 = 2\pi \sqrt{a_1^3/\mu}$$

$$T_2 = 2\pi \sqrt{a_2^3/\mu}$$

$$T_2/T_1 = (a_2/a_1)^{3/2}$$

$$= \left(\frac{24000}{18000}\right)^{3/2}$$

$$= (4/3)^{3/2} = 1.54$$

Thus orbital period of satellite-2 is 1.54 times the orbital period of satellite-1.

Problem-8 :

Determine the escape velocity for an object to be launched from surface of earth from a point where earth's radius is 6360 km. ($G = 6.67 \times 10^{-11}$ Nm^2/kg^2 and $M = 5.98 \times 10^{24}$ kg)

Solution :

$$\text{Escape velocity} = \sqrt{\frac{2\mu}{r}}$$

Here $r = 6360\text{ km} = 6360 \times 10^3\text{ m}$

$$\mu = GM = 6.67 \times 10^{-11} \times 5.98 \times 10^{24}$$

$$= 39.8 \times 10^{13}\text{ Nm}^2/\text{Kg}$$

$$\text{Therefore, Escape Velocity} = \sqrt{\frac{2 \times 39.8 \times 10^{13}}{6360 \times 10^3}}$$

$$= \sqrt{\frac{79.6 \times 10^{10}}{6360}}$$

$$= 11.2\text{ Km/s}$$

Problem - 9 :

Calculate the orbital period of a satellite in an eccentric elliptical orbit shown in Fig. 20.6.

Solution :

Semi major axis, $a = \frac{50000}{2} = 25000\text{ km}$

Orbital time period, $T = 2\pi\sqrt{\frac{a^3}{\mu}}$

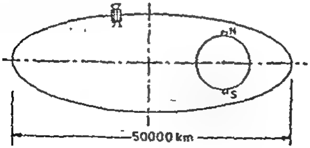


Fig. 20 6

$$\mu = GM = 6.67 \times 10^{-11} \times 5.98 \times 10^{24}$$

$$= 39.8 \times 10^{13}\text{ Nm}^2/\text{Kg}$$

$$T = 2 \times 3.14 \sqrt{\frac{(25000 \times 10^3)^3}{39.8 \times 10^{13}}}$$

$$= 6.28 \sqrt{\frac{15625 \times 10^{18}}{39.8 \times 10^{13}}}$$

$$= 6.28 \times 6.25 \times 10^3$$

$$= 39250 \text{ seconds}$$

$$= 10 \text{ hours } 54 \text{ minutes.}$$

Problem - 10 :

A satellite moving in a highly eccentric Molniya orbit having the farthest and the closest points as 35000 km and 500 km respectively from the surface of the earth. Determine the orbital time period and the velocity at the apogee and perigee points (Assume earth's radius = 6360 km).

Solution :

Apogee distance $= 35000 + 6360$

$= 41360$ km

Perigee distance $= 500 + 6360$

$= 6860$ km

Semi-major axis of elliptical orbit, $a = \frac{41360 + 6860}{2}$

$= 24110$ km

Orbital time period, $T = 2\pi \sqrt{\frac{a^3}{\mu}}$

$$= 6.28 \sqrt{\frac{(24110 \times 10^3)^3}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}}$$

$= 10$ hrs 20 minutes

Velocity at any point on the orbit is given by:

$V = \sqrt{\mu \{(2/r) - (1/a)\}}$

$$V = GM = 6.67 \times 10^{-11} \times 5.98 \times 10^{24} = 39.8 \times 10^{13}\ \text{Nm}^2/\text{Kg}$$

At Apogee point, $r = 41360$ km.

$$V = \sqrt{39.8 \times 10^{13}\left[\frac{2}{41360 \times 10^3} - \frac{1}{24110 \times 10^3}\right]}$$

$$= \sqrt{39.8 \times 10^{13}\left[\frac{48220 - 41360}{41360 \times 24110 \times 10^3}\right]}$$

$$= \sqrt{\frac{39.8 \times 10^{13} \times 6860}{41360 \times 24110 \times 10^3}}$$

$= 523$ m/s

At perigee point, $r = 6860$ km

$$\text{Therefore, } \vartheta \sqrt{39.8 \times 10^{13}\left[\frac{2}{6860 \times 10^3} - \frac{1}{24110 \times 10^3}\right]}$$

$$= \sqrt{39.8 \times 10^{13}\left[\frac{48220 - 6860}{6860 \times 24110 \times 10^3}\right]}$$

$$= \sqrt{\frac{39.8 \times 10^{13} \times 41360}{6860 \times 24110 \times 10^3}}$$

$= 9.976$ Km/s.

Problem - 11 :

The sum of apogee and perigee distances of a certain elliptical satellite orbit is 50000 km and the difference of apogee and perigee distances is 30000 kms. Determine the target eccentricity (e).

Solution :

If (r_a) and (r_p) are the apogee and perigee distances, then

$$e = \left(\frac{r_a - r_p}{r_a + r_p}\right) = \frac{30000}{50000}$$

$= 0.6.$

Problem - 12 :

The semi - major axis and the semi - minor axis of an elliptical satellite orbit are 20,000 km and 16000 km respectively. Determine the apogee and perigee distances.

Solution :

If (r_a) and (r_p) are apogee and perigee distances respectively,

then, semi-major axis $= \frac{r_a + r_p}{2}$

Semi-minor axis $= \sqrt{r_a \, r_p}$

$$\frac{r_a + r_p}{2} = 20000 \text{ km}$$

Therefore, $r_a + r_p = 40000$ km

$$\sqrt{r_a \times r_p} = 16000$$

Therefore, $r_a \, r_p = 256000000$

Now $\quad r_a + r_p = 40000 \quad$ ...(1)

$\quad r_a \times r_p = 256000000 \quad$ ...(2)

Substituting the value of (r_p) from (2) in (1)

$$r_a\,(40000 - r_a) = 256000000$$

or $\quad r_a^2 - 40000\, r_a + 256000000 = 0$

$$r_a = \frac{40000 \pm \sqrt{16 \times 10^8 - 10.24 \times 10^8}}{2}$$

$$= \frac{40000 \pm \sqrt{5.76 \times 10^8}}{2}$$

$$= \frac{40000 \pm 2.4 \times 10^4}{2}$$

$$= 3.2 \times 10^4,\ 1.6 \times 10^4$$

$$= 32000 \text{ km},\ 16000 \text{ km}$$

$r_a = 32000$ km as it cannot be 16000 km if the semi - major axis is 20,000 km.

$$r_p = 40000 - 32000 = 8000 \text{ km}$$

Problem - 13 :

A satellite is moving in a near earth circular orbit at a distance of 640 km. Determine its orbital period. (Assume R = 6360 km)

Solution :

$$\text{Orbital velocity} = \sqrt{\frac{GM}{(R+H)}}$$

$$= \sqrt{\frac{6.67 \times 10^{-11} \times 5.98 \times 10^{24}}{7000 \times 10^{3}}}$$

$$= \sqrt{\frac{39.8 \times 10^{13}}{7 \times 10^{6}}}$$

$$= 7.54 \text{ km/s.}$$

$$\text{Orbital period} = \frac{2\pi (R+H)}{V}$$

$$= \frac{6.28 \times 7000}{7.54}$$

$$= 5830 \text{ secs}$$

$$= 1 \text{ hour } 37 \text{ minutes.}$$

Problem - 14 :

A satellite moving in an eccentric elliptical orbit has semi-major axis and semi - minor axis of (a) and (b) respectively and an

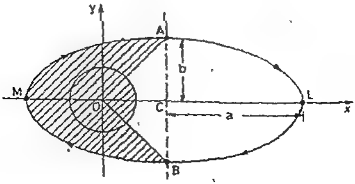


Fig. 20.7

eccentricity of 0.6. The satellite takes 3 hrs 10 minutes in moving from B to A in the direction shown. What will be the time taken by the satellite to move from A to B in the direction shown in Fig. 20.7.

Solution :

According to Kepler's law for elliptical satellite orbits, the line joining the satellite and the center of the earth spans equal ellipse area in equal time.

As a first step, we shall determine the area spanned while moving from B to A. It is given by shaded region and is given by.

Area of half of ellipse – Area of ΔAOB

$$= \frac{\pi a b}{2} - b \times OC$$

$$= \frac{\pi ab}{2} - bae$$

$$= ab\,(\pi/2 - e) = ab\left(\frac{3.14}{2} - 0.6\right)$$

$$= 0.97ab$$

$$\cong ab$$

The area spanned in moving from A to B.

$$= \frac{\pi ab}{2} + 0.6ab$$

$$= ab\,(\pi/2 + 0.6) = 2.2\,ab.$$

The ratio of the two areas is $\frac{2.2\,ab}{ab} = 2.2.$

Therefore the time taken by satellite to move form A to B should be 2.2 times the time taken by the satellite to move from B to A in the direction shown.

or time taken $= 2.2 \times 3$ hrs 10 min

$= 7$ hrs

Problem - 15 :

For an eccentric elliptical satellite orbit with an apogee and perigee points at a distance of 50,000 km and 8000 km respectively from the center of earth. Determine the semi-major axis, semi-minor axis and the orbit eccentricity.

Solution :

Apogee distance, $r_a = 50000$ km

Perigee distance, $r_p = 8000$ km

Semi-major axis, $a = \frac{r_a + r_p}{2}$

$= \frac{50000 + 8000}{2} = 29000$ km

Semi-minor axis, $b = \sqrt{r_a \times r_p}$

$= \sqrt{50000 \times 8000}$

$= 20000$ km

Orbit eccentricity, $e = \left(\frac{r_a - r_p}{r_a + r_p}\right)$

$= \left(\frac{50000 - 8000}{50000 + 8000}\right)$

$= \frac{42000}{58000}$

$= 0.724$

Problem - 16 :

Satellite - 1 and Satellite - 2 are orbitting in different elliptical orbits with same perigee but different apogee distances as shown in Fig. 20.8. The semi-major axes of the two orbits are 16000 km and 24000 km. If the orbital period of satellite - 1 is 10 hours, determine the orbital period of satellite - 2.

Solution :

Orbital period (T) is given by

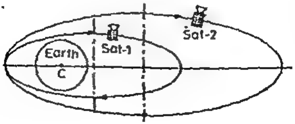


Fig. 20.8

$$T = 2\pi\sqrt{\frac{a^3}{\mu}}$$

where a = semi-major axis

$\mu = GM$

If (T_1) and (T_2) are the orbital periods of satellite-1 and satellite - 2 respectively, then

$$\left(\frac{T_2}{T_1}\right) = \frac{2\pi\sqrt{a_2^3/\mu}}{2\pi\sqrt{a_1^3/\mu}}$$

$$= \left(\frac{a_2}{a_1}\right)^{3/2}$$

$$T_2 = T_1\left(\frac{a_2}{a_1}\right)^{3/2} = 10\left(\frac{24000}{16000}\right)^{3/2}$$

$$= 10(1.5)^{3/2}$$

$$= 18.37 \text{ hours}$$

Problem - 17 :

A geosynchronous satellite moving in an equatorial circular orbit at a height of 35800 km above the surface of earth gets inclined at an angle of 2° due to some reasons. Calculate the maximum deviation in latitude and also the maximum deviation in longitude (with reference to longitude of ascending node). Also determine maximum displacements in kms caused by latitude and longitude displacements. (Assume earth's radius = 6364 km).

Solution :

Height of orbit = 35800 km

Earth's radius = 6364 km

Therefore, Orbit radius, r = 35800 + 6364

= 42164 km

Angle of inclination = 2°

Maximum latitude deviation from equator due to inclination (i) is given by :

$$\lambda_{max} = i = 2°$$

Maximum longitude deviation from ascending node, ψ_{max} is given by :

$$\psi_{max} \approx \frac{i^2}{228} = \frac{2^2}{228} = \frac{4}{228}$$

$$= 0.0175^\circ$$

Maximum displacement (in km) due to λ_{max} is given by :

$$D_\lambda \text{ (max)} = a\, i \left(\frac{\pi}{180}\right) \text{where } (i) \text{ is in deg}$$

$$= \frac{42164 \times 2 \times \pi}{180}$$

$$= 1471 \text{ km.}$$

Maximum displacement (D_ψ) due to (ψ_{max}) i given by :

$$D_\psi = D_\lambda \left(\frac{\psi_{max}}{\lambda_{max}}\right)$$

$$= 1471 \times \frac{0.0175}{2}$$

$$= 12.9 \text{ km}$$

Problem - 18 :

Determine the magnitude of velocity impulse needed to correct the inclination of 2° in the satellite orbit of problem - 17.

Solution :

The magnitude of velocity impulse is given by :

$$\sqrt{\frac{\mu}{r}} \tan i$$

$$= \sqrt{\frac{39.8 \times 10^{13}}{42164 \times 10^3}} \quad \tan 2^\circ$$

$$= 107 \text{ m/s.}$$

Problem - 19 :

A geosynchronous satellite orbitting at 42164 km from earth's center has a circular and equatorial orbit. The orbit gets inclined due to some reason and it is observed that the maximum displacement

due to latitude deviation is 500 km. Determine angle of inclination (i) between the new orbital plane and the equatorial plane.

Solution :

Maximum displacement D_λ (max) due to latitude deviation is given by:

$$D_\lambda\,(\max) = r\,\lambda_{max}$$

where λ_{max} = maximum latitude deviation

$= i$ (angle of inclination)

or $D_\lambda\,(\max) = r \times i$

$$i = D_\lambda\,(\max)/r = \frac{500}{42164} = 0.012 \text{ rad}$$

$$= 0.68\text{deg}$$

Problem - 20 :

A geostationary satellite moving in an equatorial circular orbit is at a height of 35786 km. from earth's surface. If the earth's radius is taken as 6378 km, determine the theoretical maximum coverage angle. Also determine the maximum slant range.

Solution :

For theoretical maximum coverage angle, elevation angle, E = 0. Maximum coverage angle, $2 \propto_{\max} = 2\sin^{-1}\left(\frac{R_e}{R_e+H}\cos E\right)$

where R_e = *earth's radius*

H = height of satellite above earth's surface

$$2 \propto_{max} = 2\sin\left(\frac{6378}{35786+6378}\cos 0^\circ\right)$$

$$= 17.4^\circ$$

If (D) is the maximum slant range, then

$$D^2 = R_e^2 + \left(R_e+H\right)^2 - 2R_e\,(R_e+H)$$

$$Sin\left[E + \sin^{-1}\left(\frac{R_e}{R_e+H}\cos E\right)\right]$$

$$= (6378)^2 + (42164)^2 - 2\times 6378\times 42164\times \sin 8\ 7^\circ$$

$$= 40678884 + 1777802896 - 537843984 \times 0.1512$$

$$= 1737139041$$

$$D = 41679 \text{ km}$$

Problem - 21 :

What would be the new maximum coverage angle and the slant range if the minimum possible elevation angle is 5° and not zero as in problem - 20 (Refer to Fig. 20.9).

Solution :

The maximum coverage angle, ($2 \propto_{max}$) is given by

$$2 \propto_{max} = 2 \sin^{-1}\left[\left(\frac{Re}{Re + H}\right)\cos E_{min}\right]$$

where E_{min} = Minimum elevation angle

$$2 \propto_{max} = 2 \sin^{-1}\left[\left(\frac{6378}{6378 + 35786}\right)\cos 5^\circ\right]$$

$$= 2 \sin^{-1} [0.1512 \times 0.996]$$

$$= 2 \sin^{-1} 0.1506$$

$$= 2 \times 8.66$$

$$= 17.32^\circ$$

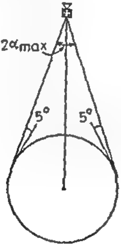


Fig 20.9

Problem - 22 :

Refer to Fig. 20.10 showing a geostationary satellite orbitting earth. Calculate the angle (θ) subtended by the arc of the satellite's footprint at the center of earth.

Solution :

$$\theta = \theta_1 + \theta_2$$

$$\theta_1 = 90^\circ - \alpha_1 - E_1 \qquad (E_1 = 5^\circ)$$

$$\sin\left[5^\circ + \sin^{-1}\left(\frac{6378}{6378+35786}\cos 5^\circ\right)\right]$$

$= 40678884 + 1777802896 - 126984965$

$= 1691496815$

Therefore, $d = \sqrt{1691496815}$

$= 41127.8$ km

Round trip time, $\tau = \frac{2d}{c}$

where $c = 3 \times 10^8$ m/s $= 3 \times 10^5$ km/s

$$\tau = \frac{2 \times 41127.8}{3 \times 10^5} \text{ secs}$$

$$= 0.274 \text{ sec}$$

$$= 274 \text{ ms}$$

Problem - 24 :

Determine the maximum shadow angle that occurs at equinoxes for a satellite orbitting in a circular equatorial orbit at a height of 13622 km above the surface of earth. Assume earth's radius to be 6378 km. Also determine the maximum daily eclipse duration.

Solution :

Refer to Fig. 20.11

The radius of circular orbit = 13622 + 6378

= 20,000 km

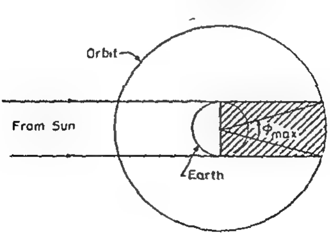


Fig 20.11

Maximum shadow angle, $\phi_{max} = 180^\circ - 2\cos^{-1}\left(\frac{6378}{20,000}\right)$

$$\phi_{max} = 180^\circ - 2\cos^{-1} 0.3189$$

$$= 180^\circ - 2 \times 71.4$$

$$= 180^\circ - 142.8$$

$$= 37.2^\circ$$

Maximum daily eclipse duration $= \frac{37.2}{360} \times 24$ hours

$= 2.48$ hours

Problem - 25 :

We know that the first day of eclipse before an equinox and last day of the eclipse after an equinox correspond to the relative position

Also determine the same for a geostationary orbit at a height of 35786 km above earth's surface.

Solution :

The angle of inclination $i_e(t)$ between the equatorial plane and the direction of sun as a function of time during the time period of earth's one rotation around sun is given by

$$i_e(t) = 23.4 \sin \frac{2\pi t}{T}$$

where $T = 365$ days

23.4° is the maximum inclination that occurs on summer and winter solstices.

For a circular orbit of 20,000 km radius, $\phi = 37.4^\circ$. Therefore, the time from first day of eclipse to the equinox is given by substituting $i_e(t) = 18.7^\circ$ ($=37.4^\circ/2$)

i.e. $$18.7 = 23.4 \sin \frac{2\pi t}{365}$$

or $$t = \frac{365}{2\pi} \sin^{-1}\left(\frac{18.7}{23.4}\right)$$

$$= \frac{365}{2\pi}(53^\circ)$$

$$= \frac{365}{2\pi} \times 53 \times \frac{\pi}{180} = 53.8 \text{ days}$$

For the geostationary orbit,

$$\phi_{max} = 180^\circ - 2\cos^{-1}\left(\frac{6378}{6378 + 35786}\right)$$

$$= 180^\circ - 2\cos^{-1} 0.1512$$

$$= 180^\circ - 2 \times 81.3^\circ$$

$$= 180^\circ - 162.6^\circ$$

$$= 17.4^\circ$$

Therefore, $t = \frac{365}{\pi}\sin^{-1}\left(\frac{8.7}{23.4}\right)$

$$= \frac{365}{\pi}(21^\circ)$$

$$= \frac{365}{\pi} \times 21 \times \frac{\pi}{180} \text{ days}$$

$$= 22.13 \text{ days}$$

Problem - 26 :

A satellite is currently in its elliptical transfer orbit (Fig. 20.12) with apogee and perigee being at distances of 35786 km and 300 km respectively above the surface of earth. If the transfer orbit inclination to the equatorial plane is 0°, calculate the incremental velocity to be given to the satellite at the apogee point by the apogee kick motor to circularize the orbit (Assume earth's radius = 6378 km)

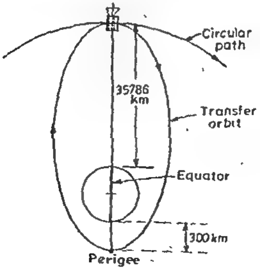


Fig 20.12

Solution :

The velocity (V) at any point along an elliptical orbit is given by:

$$V = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$$

where $\mu = GM$

r = apogee distance from center of earth

a = semi-major axis of ellipse

Now $r = 35786 + 6378 = 42164$ km

$$a = \frac{35786 + 6378 + 6378 + 300}{2} = 24421 \text{ km}$$

The velocity (V_a) at the apogee point can then be computed from

$$V_a = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$$

$$V_a^2 = 39.8 \times 10^{13}\left(\frac{2}{42164} \times 10^{13} - \frac{1}{24421} \times 10^3\right)$$

$$= \frac{39.8 \times 10^{13} \times 6678}{42164 \times 24421 \times 10^3}$$

$$V_a^2 = 2.58 \times 10^6$$

$$V_a = \sqrt{2.58 \times 10^6} = 1.61 \text{ km/s}$$

For a circular orbit with a radius of 42164 km,

$$V_c = \sqrt{\frac{\mu}{r}} = \sqrt{\frac{39.8 \times 10^{13}}{42164 \times 10^3}}$$

$$= 3.07 \text{ km/s}$$

The velocity change (ΔV) required to circularize is given by

$$\Delta V = \sqrt{V_a^2 + V_c^2 - 2\, V_a\, V_c \cos i}$$

Here $i = 0^\circ$

Therefore, $\Delta V = \sqrt{V_a^2 + V_c^2 - 2\, V_a V_c}$

$$= \sqrt{\left(V_a - V_c\right)^2}$$

$$= \left(V_a - V_c\right) \text{or} \left(V_c - V_a\right)$$

$= 3.07 - 1.61$

$= 1.46$ km/s

Problem - 27 :

If the satellite in Problem - 26 was launched from cape Kennedy having a latitude of 28° N and if the injection of the satellite at perigee point was horizontal, determine the velocity change required to circularize the orbit and correct the inclination.

Solution :

The elliptical transfer orbit has an inclination that is equal to or greater than the launch point latitude. If the satellite injection is horizontal at the perigee, it equals the launch point latitude.

Here $i = 28°$

Therefore, $\Delta V = \sqrt{(1.61)^2 + (3.07)^2 - 2 \times 1.61 \times 3.07 \times \cos 28°}$

$= \sqrt{2.59 + 9.42 - 8.73}$

$= \sqrt{3.276}$

$= 1.81$ Km/s

Problem - 28 :

Determine the maximum line of sight distance between two communication satellites moving in a circular orbit at aheight (H) above the surface of earth.

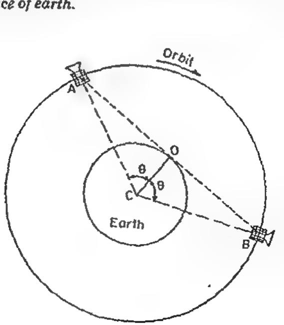


Fig. 20.13

Solution :

Maximum line of sight distance between the two satellites would occur when the satellites are so placed that the line joining the two becomes tangent to the earth's surface as shown in Fig. 20.13.

Maximum line of sight distance = AB = OA + OB = 2 × 0 A or 2 × 0 B as OA = OB. If (R) is the radius of earth and (H) the height of the orbit, then

$$OA = AC \sin\theta$$
$$= (R+H)\sin\theta$$

Now $\theta = \cos^{-1}\left(\frac{R}{R+H}\right)$

Therefore, $OA = (R+H)\sin\left(\cos^{-1}\frac{R}{R+H}\right)$

Maximum line of distance $= 2(R+H)\sin\left[\cos^{-1}\left(\frac{R}{R+H}\right)\right]$

Problem - 29 :

If the two satellites in Problem - 28 have an orbital radius that is twice the radius of earth, determine the maximum line of sight distance. Repeat the problem for geostationary satellites having an orbital radius of 42164 km. (Assume earth's radius, R = 6370 km)

Solution :

Maximum line of sight distance $= 2(R+H)\sin\left[\cos^{-1}\left(\frac{R}{R+H}\right)\right]$

It is given that $(R+H) = 2R$

Therefore, maximum line of sight distance

$$= 2 \times 2R \sin\left[\cos^{-1} 0\,5\right]$$
$$= 4\,R \sin 60^\circ$$
$$= \frac{4\sqrt{3}}{2} R = 2\sqrt{3}\,R$$
$$= 2\sqrt{3} \times 6370$$
$$= 22066 \text{ km}$$

For geostationary satellites, $(R+H) = 42164$ km

Therefore, maximum line of sight distance =

$$2 \times 42164 \sin\left(\cos^{-1}\frac{6370}{42164}\right)$$

$$= 84328 \sin(\cos^{-1} 81.3)$$

$$= 84328 \times 0.993$$

$$= 83361 \text{ km}$$

Problem - 30 :

Two communication satellites in the same circular orbit but located at 130° W and 70°W longitudes communicate via an inter-satellite link. Find the round trip propagation delay.

Solution :

The angular difference in the longitudes of the two satellites

$$= 130°W - 70°W = 60°$$

Also, a longitudinal difference of 180° corresponds to the two satellites located diametrically opposite to each other. The current situation is depicted in Fig. 20.14.

The line-of-sight distance between the two satellites can be computed from triangle ABC where

$$AB = \sqrt{AC^2 + BC^2 - 2AC \times BC \cos 60°}$$

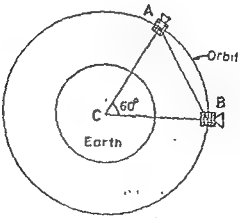


Fig 20 14

Here AC = BC = R ...... (orbital radius)

Therefore $AB = \sqrt{R^2 + R^2 - 2R^2 \times 0.5} = R$

$$\text{Round trip time} = \frac{2R}{3 \times 10^8} \quad \text{where (R) is in meters}$$

Problem - 31 :

If the location of the two satellites in Problem - 30 was 30°W and 15°E and if the orbital radius was 10000 km, determine the round trip propagation delay.

Solution :

The angular difference = 30° + 15° = 45°

The two figures have been added as one satellite is towards west of the reference while the other is towards east.

Line-of-sight distance

$$= \sqrt{(10000)^2 + (10000)^2 - 2 \times (10000)^2 \cos 45^\circ}$$

$$= \sqrt{10^8 + 10^8 - 1.41 \times 10^8} = 0.765 \times 10^4 \text{ km}$$

$$= 7650 \text{ km}$$

$$\text{Round trip propagation delay} = \frac{2 \times 7650}{3 \times 10^5} \text{ sec} = 51 \text{ ms}$$

Problem - 32 :

An earth station is located at 30°W longitude and 60°N latitude. Determine the earth station azimuth and elevation angles with respect to geostationary satellite located at 50°W longitude (Assume orbital radius = 42164 km and earth's radius = 6378 km)

Solution :

Earth station azimuth angle, $A = 180^\circ - A'$ if the earth station is in the northern hemisphere and is towards the west of the satellite.

$$A' = \tan^{-1}\left[\frac{\tan|\theta_S - \theta_L|}{\sin \theta_l}\right]$$

where θ_s = satellite longitude

θ_L = earth station longitude

θ_l = earth station latitude

$$A' = \tan^{-1}\left[\frac{\tan 20^\circ}{\sin 60^\circ}\right] = 22.8^\circ$$

Therefore, azimuth, $A = 180^\circ - 22.8^\circ = 157.2^\circ$

The earth station elevation angle is given by

$$E = \tan^{-1}\left[\frac{r - R_e \cos\theta_l \cos|\theta_s - \theta_L|}{R_e \sin\left(\cos^{-1}\cos\theta_l \cos|\theta_s - \theta_L|\right)}\right] - \cos^{-1}\{\cos\theta_l \cos|\theta_s - \theta_L|\}$$

where r = orbital radius

R_e = earth's radius

$$E = \tan^{-1}\left[\frac{42164 - 6378\cos 60^\circ \cos 20^\circ}{6378 \sin\left[\cos^{-1}(\cos 60^\circ \cos 20^\circ)\right]}\right] - \cos^{-1}(\cos 60^\circ \cos 20^\circ)$$

$$= \tan^{-1}\left(\frac{42164 - 2998}{6378 \sin(\cos^{-1} 0.47)}\right) - \cos^{-1} 0.47$$

$$= \tan^{-1}\left(\frac{39166}{5631}\right) - 62^\circ$$

$$= 81.8^\circ - 62^\circ = 19.8^\circ$$

Azimuth = 157.2°, Elevation = 19.8°

Problem - 33 :

A satellite is in a circular equatorial orbit at an altitude of 10000 km from earth's surface. Determine the maximum eclipse time in a day during the full eclipse period (Assume earth's radius = 6378 km)

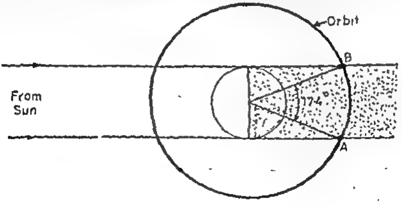


Fig 20.15

Solution :

The maximum shadow angle and consequently the maximum daily eclipse duration occurs at equinoxes i.e. when the earth's equatorial plane's inclination to the direction of the sun is 0° (Fig. 20 15)

The shadow angle in this case is given by

$$\phi_{max} = 180^\circ - 2\cos^{-1}\left(\frac{R_e}{R_e + H}\right)$$

where Re = earth's radius

H = height of satellite orbit

Substituting the values of (Re) and (H)

$$\phi_{max} = 180^\circ - 2\cos^{-1}\left(\frac{6378}{6378 + 10000}\right)$$

$$= 180^\circ - 2\cos^{-1} 0.389$$

$$= 180^\circ - 2 \times 67^\circ$$

$$= 46^\circ$$

The eclipse duration is the time taken by the satellite to move from point A to B (Fig. 20.15)

Therefore eclipse duration $= \frac{46}{360} \times$ orbital period

Now orbital period $= 2\pi\sqrt{a^3/\mu}$

where (a) here is the orbital radius

Orbital period $\approx 2\pi\sqrt{\frac{(16378 \times 10^3)^3}{39.8 \times 10^{13}}}$

≈ 5.8 hours

Therefore, eclipse duration $\approx \frac{46}{360} \times 5.8$

≈ 0.74 hours

≈ 44.5 minutes

Problem 34 :

A geostationary satellite launched by ESA's Ariane rocket from Kourou in French Guiana has the perigee of its elliptical transfer orbit at 450 km. Find the incremental velocity required to correct the orbit inclination and to achieve orbit circularization given that Kourou is located at 5.3°N latitude and also that the line joining the apogee and perigee is the node line (line joining ascending and descending nodes).

Solution :

The orbit circularization manoeuvre is carried out at the apogee point and if the line joining the apogee and the perigee happens to be the nodal line, then the incremental velocity required to correct the inclination and circularize the orbit is given by

$$\Delta V = \sqrt{V_a^2 + V_c^2 - 2V_aV_c \cos i}$$

where V_a = velocity at apogee

= 1.61 km/s for geostationary orbit

V_c = velocity of circular geostationary orbit

= 3.07 km/s

i = inclination angle = 5.3°

(V_a) and (V_c) have been computed in an earlier problem. Inclination angle being equal to the latitude of the launch point has also been explained.

$$\Delta V = \sqrt{(1.61)^2 + (3.07)^2 - 2 \times 1.61 \times 3.07 \cos 5.3^\circ}$$

$$= \sqrt{2.59 + 9.42 - 9.88 \times 0.995}$$

$$= \sqrt{2.59 + 9.42 - 9.837}$$

$$= \sqrt{2.173} = 1.474 \text{ Km/s}$$

Problem - 35 :

Consider two earth stations A and B with longitudes at 60° W and 90° W respectively and latitudes at 30° N and 45° N respectively. They are communicating with each other via a geostationary satellite located at 105°W. Find the total delay in sending 500 kilobits of information from one station to the other if the transmission speed is 10 Mbps. (Assume satellite orbital radius = 42164 km and earth's radius = 6378 km)

Solution :

Earth station A latitude, $\theta_{lA} = 30°$

Earth station A longitude, $\theta_{LA} = 60°$

Satellite longitude, $\theta_s = 105°$

The elevation angle of earth station A, E_A =

$$\tan^{-1}\left[\frac{42164\times10^3-6378\times10^3\cos 30^\circ\cos 45^\circ}{6378\times10^3\sin\{\cos^{-1}(\cos 30^\circ\cos 45^\circ)\}}\right]$$

$$-\cos^{-1}(\cos 30^\circ\cos 45^\circ)$$

$$=\tan^{-1}\left[\frac{42164-6378\times0.612}{6378\times\sin 52.2^\circ}\right]-\cos^{-1}0.612$$

$$=\tan^{-1}\left[\frac{38260}{5039}\right]-52.2^\circ$$

$$=82.5^\circ-52.2^\circ=30.3^\circ$$

Earth station B latitude, $\theta_{lB}=45^\circ N$

Earth station B longitude, $\theta_{LB}=90^\circ W$

The elevation angle of earth station B, $E_B=$

$$\tan^{-1}\left[\frac{42164\times10^3-6378\times10^3\cos 45^\circ\cos 15^\circ}{6378\times10^3\sin\{\cos^{-1}(\cos 45^\circ\cos 15^\circ)\}}\right]$$

$$-\cos^{-1}(\cos 45^\circ\cos 15^\circ)$$

$$=\tan^{-1}\left[\frac{42164-6378\times0.682}{6378\sin(\cos^{-1}0.682)}\right]-\cos^{-1}(0.682)$$

$$=\tan^{-1}\left[\frac{37814}{4656}\right]-47^\circ$$

$$=83^\circ-47^\circ=36^\circ$$

In the next step, we shall determine the slant range of the earth stations.

Refer to Fig. 20.16. The slant range (d_A) of the earth station A can be computed from:

$$d_A^2=\left(42164\times10^3\right)^2+\left(6378\times10^3\right)^2-2\times6378\times42164\times10^6\times\sin\left[30.3^\circ+\sin^{-1}\left\{\frac{6378}{42164}\cos 30.3^\circ\right\}\right]$$

$$=1777802896\times10^6+40678884\times10^6-537843984\times10^6\times\sin 37.8^\circ$$

$$=1488833409\times10^6$$

$$d_A=\sqrt{14888833409\times10^6}=38585\text{ Km}$$

The slant range (d_B) of the earth station B can be computed from:

$$d_B^2=(42164\times10^3)^2+(6378\times10^3)^2-2\times6378\times42164\times10^{■}\times$$

$$\sin\left[36^\circ + \sin-1\left\{\frac{6378}{42164}\cos 36^\circ\right\}\right]$$

$$= 1777802896 \times 10^6 + 40678884 \times 10^6$$

$$- 537843984 \times 10^6 \sin 43^\circ$$

$$= \sqrt{1451673065 \times 10^6} = 38101 \text{ Km}$$

Total range to be covered $= 38585 + 38101$

$= 76686$ km

Propagation delay $\approx \frac{76686}{3 \times 10^5} = 255.6$ ms

The time required to transmit 500 Kbps at a transmission speed of 10 Mbps is given by

$$\frac{500000}{10^7} \text{ sec} = 50 \text{ ms}$$

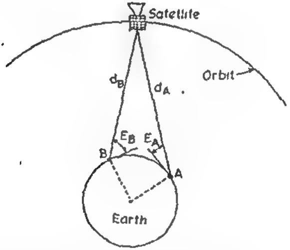


Fig. 20 16

Therefore, total propagation delay $= 255\ 6 + 50$

$= 305.6$ ms

Problem - 36 :

Calculate the power gain of a paraboloid reflector antenna with a mouth diameter of 10 m at 6 GHz. Assume antenna aperture efficiency to be 80%.

Solution :

Mouth diameter, D = 10 m

Frequency, $f = 6$ GHz

Aperture efficiency , $\eta = 0.8$

Antenna gain (G) *is given by*

$$G = \eta \frac{4\pi A}{\lambda^2}$$

where A = aperture area $= \frac{\pi D^2}{4} = \frac{\pi \times (10)^2}{4} = 78.5 \text{ m}^2$

$$\lambda = \text{wavelength} = \frac{c}{f} = \frac{3 \times 10^8}{6 \times 10^9} = 0.05 \text{ m}$$

Therefore, $G = \frac{0.8 \times 4 \times 3.14 \times 78.5}{0.05 \times 0.05}$

$= 315507$

Gain in decibels $= 10 \log 315507$

$= 10 \times 5.5$

$= 55$ dB

Problem - 37 :

[illegible] has [illegible] in [illegible]

Solution :

The power gain (G) if the antenna is also given by:

$$G = \frac{4\pi}{\Delta\theta \, \Delta\phi}$$

where $\Delta\theta$ = azimuth beamwidth in radians

$\Delta\phi$ = elevation beamwidth in radians

In the present case, $G = 315507$

$$\Delta\theta = 1^\circ = \frac{\pi}{180} \text{ rad}$$

Therefore, $\Delta\phi = \frac{4\pi}{G \, \Delta\theta}$

$$= \frac{4\pi \times 180}{315507 \times \pi} = \frac{720}{315507} \text{ rad}$$

$$= \frac{720 \times 180}{315507 \times \pi} \text{ deg}$$

$$= 0.13 \text{ deg}$$

Problem - 38 :

A paraboloid dish antenna having a mouth diameter of 20 m and an aperture efficiency of 90% produces a radiated beam with a solid angle of 3×10^{-4} steradians. Determine the antenna's power gain in decibels and also the operational frequency.

Solution :

Solid angle of the antenna beam = 3×10^{-4} steradians

Power gain, $G = \frac{4\pi}{\Omega}$

where Ω = beam solid angle in steradians

Therefore, $G = \frac{4\pi}{3 \times 10^{-4}} = 41904$

Power gain in decibels = 10 log 41904

$= 10 \times 4.622 \quad = 46.22$ dB

Power gain is also expressed by

$$G = \eta \frac{4\pi A}{\lambda^2}$$

where A = antenna's area of crossection

λ = operational wavelength

η = aperture efficiency

Therefore $G = \frac{0.90 \times 4 \times \pi \times \pi \times (20)^2}{4\lambda^2} = 41904$

or $$\lambda^2 = \frac{0.9 \times 4\pi^2 \times 400}{4 \times 41904} = 0.0847$$

$$\lambda = \sqrt{0.0847} = 0.291 \text{ m}$$

Operational frequency, $f = \frac{c}{\lambda} = \frac{3 \times 10^8}{0.291}$

$= 1030.92$ MHz

Problem - 39 :

A Ku-band 20 m Cassegrain antenna designed for a satellite earth station has the following specifications for the antenna efficiency

Parameter	Operational Frequency 11.95 GHz	14.25 GHz
Illumination efficiency	0.98	0 96
Spillover efficiency		
Main reflector	0.99	0.99
Sub reflector	0.97	0.97
Blocking efficiency	0.85	0.85
Feed system efficiency	0.90	0.90
Surface tolerance efficiency	0.92	0.92

Determine antenna's power gain at 11.95 GHz and 14.25 GHz.

Solution :

Power gain (G) is given by:

$$G = \eta \frac{4\pi A}{\lambda^2}$$

$$A = \frac{\pi D^2}{4} = \frac{\pi \times 400}{4} = 314 \text{ m}^2$$

(i) For $f = 11.95$ GHz

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{11\ 95 \times 10^9} = 0\ 0251 \text{ m}$$

$$\eta = 0.98 \times 0.99 \times 0.97 \times 0.85 \times 0.90 \times 0.92$$

$$= 0.66$$

Therefore, G (at $f = 11.95$ GHz) $= \dfrac{0.66 \times 4 \times 3\ 14 \times 314}{(0.0251)^2}$

$$= 4131576$$

Gain in decibels = 10 log 4131576 = 66.16 dB

(ii) For $f = 14.25$ GHz

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{14.25 \times 10^9} = 0.021\text{m} \; \eta = 0.648$$

$$\text{Therefore, } G \text{ (at } f = 14.25 \text{ GHz)} = \frac{0.648 \times 4 \times 3.14 \times 314}{(0.021)^2}$$

$$= 5795030$$

Gain in decibels = 10 log 5795030

= 67.63 dB

Problem - 40 :

A satellite earth station antenna having a maximum gain of 60 dB at the operational frequency is fed from a power amplifier generating 10 KW. If the feed system has a loss of 2 dB, determine earth station EIRP (Effective Isotropic Radiated Power).

Solution :

Power at the output of amplifier	= 10 KW
	= 40 dBW
Antenna gain	= 60 dBW
Power loss in feed system	= 2 dBW

Therefore, $EIRP = 40 + 60 - 2 = 98$ dBW

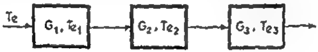


Fig. 20.17

Problem - 41 :

Fig. 20.17 shows a cascaded arrangement of three gain blocks. It is given that $G_1 = 10^6$ and its associated equivalent noise temperature $T_{e1} = 100$ deg Kelvin, $G_2 = 10^4$ and $T_{e2} = 60$ deg K, $G_3 = 1000$ and $Te_3 = 20$ deg K. Determine the equivalent noise temperature of the cascaded arrangement

Solution :

If (T_e) is the equivalent noise temperature of the cascaded, arrangement,

Then $T_e = T_{e1} + \frac{T_{e2}}{G_1} + \frac{T_{e3}}{G_1 G_2}$

$$= 100 + \frac{60}{10^6} + \frac{20}{10^6 \times 10^4}$$

$$= 100 + 60 \times 10^{-6} + 20 \times 10^{-10}$$

$$\cong 100K$$

Problem - 42 :

Fig. 20.18 shows the cascaded arrangement of four gain blocks with their gain and noise figures as $G_1 = 100$, $F_1 = 2$, $G_2 = 10$, $F_2 = 10$, $G_3 = 10$, $F_3 = 15$, $G_4 = 10$, $F_4 = 20$. Determine the noise figure of the cascaded arrangement.

Fig 20.18

Solution :

The overall noise figure (F) is given by

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3}$$

$$= 2 + \frac{10 - 1}{100} + \frac{15 - 1}{100 \times 10} + \frac{20 - 1}{100 \times 10 \times 10}$$

$$= 2 + 0.9 + 0.014 + 0.0019 \qquad = 2.1059 = 3.2 \text{ dB}$$

Problem - 43 :

Fig. 20.19 shows the receive side of satellite earth station comprising of earth station antenna followed by waveguide that connects the antenna feed point to the low noise amplifier input with the output of the low noise amplifier feeding the down-converter. Assume that the receive antanna has a gain of 66 dB at the received down link frequency of 11.9 GHz. The other parameters characterising the receive chain are :

Antenna noise temperature, $T_A = 60$ K

Loss in the waveguide, $L_1 = 1.075$ (0 3 dB)

Equivalent noise temperature of low noise amplifier. $T_{e2} = 160K$

Low noise amplifier gain, $G_2 = 10^6$

Down converter equivalent noise temperature, $T_{e3} = 10000\,K$

Ambient temperature, $T_0 = 290\,K$

Determine the earth station system noise temperature and (G/T) referred to the input of the low noise amplifier.

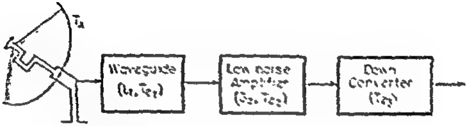


Fig. 20.19

Solution :

Earth station system noise temperature referred to the input of the low noise amplifier is given by :

$$T = T_s + T_e$$

where T_s = Noise temperature measured at the output of the waveguide

T_e = Equivalent noise temperature at the input of low noise amplifier

$$\text{Now } T_s = \frac{T_A}{L_1} + \frac{(L_1 - 1)\,T_0}{L_1}$$

$$= \frac{60}{1.075} + \left(\frac{1.075 - 1}{1.075}\right)290$$

$$= 55.81 + 20\,23 = 76\,04\text{ K}$$

$$T_e = T_{e\,2} + \frac{T_{e\,3}}{G_2}$$

$$= 160 + \frac{10000}{10^6}$$

$= 160 + 0.01 = 160.01$

Therefore, $T = 76.04 + 160.01 = 236.05$ K

The antenna gain referred to the input of the low noise *amplifier is given by*

$$G = 66 - 0.3 = 65.7 \text{ dB}$$

The antenna gain to noise temperature ratio in dB per kelvin is given by

$$\frac{G}{T} = G \text{ (in } dB) - 10 \log T$$

$$= 65.7 - 10 \log 236.05$$

$$= 65.7 - 23.73 = 41.97 \text{ dB/K}$$

Problem - 44 :

For the data given in problem - 43, determine the earth station system noise temperature and (G/T) referred to the (i) input of waveguide (ii) input of down converter. What do you deduce from the results ?

Solution :

(i) The source noise temperature in this case become (T_A). The equivalent noise temperature (Te) at the waveguide input is given by:

$$(L_1 - 1)\, T_0 + T_{e2}\, L_1 + \frac{T_{e3}\, L_1}{G_2} \quad \ldots\ldots\ldots\ldots \left(G_1 = \frac{1}{L_1}\right)$$

$$= (1.075 - 1)\, 290 + 160 \times 10.75 + \frac{10000 \times 1.075}{10^6}$$

$$= 290 \times 0.075 + 172 + 0.01$$

$$= 193.76 \text{ K}$$

Therefore, $T_s = 60 + 193.76 = 253.76$ K

In this case, $G = 66\ dB$

$$\text{Therefore } \frac{G}{T} = 66 - 10 \log 253.76$$

$$= 66 - 24.03$$

$$= 41.97 \text{ dB/K}$$

(ii) The source noise temperature is given by

$$\frac{T_A G_2}{L_1} + \left(\frac{L_1 - 1}{L_1}\right) T_0 G_2 + T_{e2} G_2 + T_{e3}$$

$$\frac{60 \times 10^6}{1.075} \times \frac{0.075}{1.075} \times 290 \times 10^6 + 160 \times 10^6 + 10^4$$

$$= 55.81 \times 10^6 + 20.23 \times 10^6 + 160 \times 10^6 + 10^4$$

$$= 236.05 \times 10^6 \text{ K}$$

Gain, $G = 66 - 0.3 + 60$

$$= 125.7 \text{ dB}$$

$$\frac{G}{T} = 125.7 - 10 \log 236.05 \times 10^6$$

$$= 125.7 - 83.73$$

$$= 41.97\, dB/K$$

The results obtained in problems - 43 and 44 prove that value of (G/T) is invariant regardless of the chosen reference point. For the given problem, (G/T) turns out to be 41.97 dB/K irrespective of whether the reference point is input of waveguide or input of low noise amplifier or input of down converter.

Problem - 45 :

Consider a dual up-converter (Fig. 20.20) with the following parameters :

Uplink frequency spectrum = 5.9 to 6.4 GHz

First intermediate frequency = 70 MHz

Carrier bandwidth = 36 MHz

BPF-1 center frequency = 1 GHz

Find (a) First local oscillator frequency (b) range of second local oscillator frequency (c) frequency spectrum of the unwanted sideband.

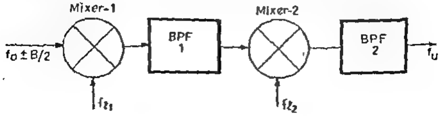


Fig. 20.20

Solution :

(a) First local oscillator frequency, $f_{l1} = 1GHz - 70MHz$

$= 930$ MHz

(b) Minimum second local oscillator frequency, f_{l2} (min) is given by

f_{l2} (min) $= 5.9 - 1 = 4.9$ GHz

Maximum second local oscillator frequency, f_{l2} (max) is given by :

f_{l2} (max) $= 6.4 - 1 = 5.4$ GHz

Second local oscillator range = 4.9 GHz to 5.4 GHz

(c) Frequency spectrum of the unwanted sideband is from :

$[f_u\ (min) - 2\ (f_{l1} + f_0)]$ to $[f_u\ (max) - 2\ (f_{l1} + f_0)]$

$= [5.9 - 2\ (0.930 + 0.070)]$ to $[6.4 - 2\ (0.930 + 0.070)]$

$= 3.9$ GHz to 4.4 GHz

Problem - 46 :

Consider a dual up-converter (Fig. 20.20) with the following specifications:

(i) Uplink frequency spectrum = 14 to 14.5 GHz

(ii) First intermediate frequency = 140 MHz

(iii) Carrier bandwidth = 72 MHz

(iv) BPF-1 center frequency = 1.19 GHz

Determine (a) first local oscillator frequency (b) range of second local oscillator frequency (c) frequency spectrum of unwanted sideband (d) bandwidths of BPF-1 and BPF-2.

Solution :

(a) First local oscillator frequency = 1190 − 140 = 1050 MHz

(b) Minimum second local oscillator frequency, f_{l2} (min) is *given by:*

f_{l2} (min) $= 14 - 1.19 = 12.81$ GHz

Maximum second local oscillator frequency, f_{l2} (max) is given by:

f_{l2} (max) $= 14.5 - 1.19 = 13.31$ GHz

Second local oscillator range is therefore 12.81 to 13.31 GHz

(c) frequency spectrum of the unwanted sideband is from

$[f_u\,(\min) - 2\,(f_{l1} + f_0)]$ to $[f_u\,(\max) - 2\,(f_{l1} + f_0)]$

$= [14 - 2\,(1050 + 140)]$ to $[14.5 - 2\,(1050 + 140)]$

$= 11.62$ to 12.12 GHz

(d) Bandwidth of BPF-1 = Bandwidth of first IF = 140 MHz

Bandwidth of

BPF – 2 = uplink frequency spectrum bandwidth

= 500 MHz

Problem - 47 :

Consider a dual Down-Converter (Fig. 20.21) with following specifications :

(i) Downlink frequency, $f_d = 4$GHz

(ii) Intermediate frequency, $f_0 = 70$MHz

(iii) Downlink frequency spectrum = 3.7 to 4.2 GHz

(iv) Carrier bandwidth = 36 MHz

Determine (a) first local oscillator frequency (b) second local oscillator frequency (c) center frequency of BPF–1 and its bandwidth.

Solution :

With reference to Fig 20.21, the sum of first and second local oscillator frequencies is given by

$$f_{l1} + f_{l2} = f_d - f_0$$

Also $(f_d - f_{l2})$ should be greater than f_d frequency spectrum bandwidth, 500 MHz in the present case

Choose $(f_d - f_{l2}) = 1$ GHz

which gives $f_{l2} = f_d - 1$ GHz $= 4 - 1 = 3$ GHz

$f_{l1} = f_d - f_0 - f_{l2} = 4 - 0.07 - 3 = 930$ MHz

Center frequency of BPF – 1 = 1GHz

Bandwidth = 36 MHz

Problem - 48 :

Consider a dual Down-Converter with the following parameters

(i) Down link frequency spectrum = 10.7 to 11.7 GHz

(ii) First local oscillator frequency = 2.1 GHz

(iii) Carrier bandwidth = 72 MHz

(iv) First intermediate frequency = 140 MHz

Determine (a) center frequency and bandwidth of BPF-1 (Fig. 20.21) (b) second local oscillator frequency range.

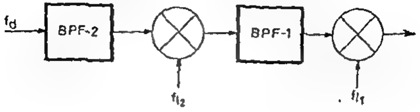


Fig 20 21

Solution :

(a) Center frequency of BPF – 1 $= f_{l1} + f_0$

$$= 2.1 + 0.140$$

$$= 2.24 \text{ GHz}$$

Bandwidth of BPF – 1 = 140 MHz

(b) Minimum second local oscillator frequency (f_{l2} (min)) is given by :

f_{l2} (min) = 10.7 – 2.24 = 8.46 GHz

f_{l2} (max) = 11.7 – 2.24 = 9.46 GHz

Second local oscillator frequency range is from 8.46 to 9.46 GHz.

Problem - 49 :

Consider the earth station receive chain as shown in Fig. 20.19. Find the system noise temperature and (G/T) as referred to the input of low noise amplifier for the specifications listed below.

Antenna gain = 55 dB

Waveguide loss = 0.1 dB

Low noise amplifier gain = 55 dB

Low noise amplifier equivalent noise temperature 45° K

Down converter equivalent noise temperature = 215000° K

Ambient temperature = 300°K

Antenna noise temperature contributors : Main beam = 25°K, Subreflector spill-over = 3.3°K, Main reflector spillover = 1°K, Blockage = 10°K and Feed loss = 15°K.

Solution :

Earth station system noise temperature referred to the input of the low noise amplifier is given by :

$$T = T_s + T_e$$

where T_s = noise temperature measured at the output of the waveguide

T_e = equivalent noise temperature at the input of low noise amplifier

Antenna noise temperature $T_A = 25 + 3.3 + 1 + 10 + 15 = 54.3°K$

Equivalent noise temperature of waveguide = $(L - 1) \times T_0$

where L = waveguide loss = 0.1 dB = 1.023

Therefore, $(L - 1)\ T_0 = (1.023 - 1) \times 300 = 6.9°K$

$$T_s = 54.3 + \frac{6.9}{1.023} = 54.3 + 6.74 = 61.04°K$$

Low noise amplifier gain = 55 dB = 316227.7

Therefore, $T_e = 45 + \dfrac{315000}{316227.7}$

$= 45 + 0.68$

$= 45.68°K$

Therefore, $T = T_s + T_e$

$= 61.04 + 45.68$

$= 106.72°K$

Gain (G) as referred to low noise amplifier input = 55 − 0.1 = 54.9 dB

Therefore, $(G/T) = 54.9 - 10 \log 106.72$

$= 54.9 - 20.28$

$= 34.62$ dB/K

Problem - 50 :

Consider the receive side of the earth station as shown in Fig. 20.19 The antenna gain is 65 dB and its noise contribution is 60°K. The waveguide loss is 0.5 dB. Determine the equivalent noise temperature of the low noise amplifier assuming that the noise contribution by the down converter is negligible and earth station (G/T) is 40 dB/K (T_0 = 300°K).

Solution :

System gain with respect to low noise amplifier input = 65 − 0.5 = 64.5 dB.

System noise with respect to low noise amplifier input, $T = T_s + T_e$

where T_s = noise contribution of antenna and waveguide

T_e = equivalent noise temperature of low noise amplifier

$$T_s = \frac{60}{L} + \left(\frac{L-1}{L}\right) \times 300$$

where $L = \text{Antilog}\,\frac{0.5}{10} = 1.122$

$$T_s = \frac{60}{1.122} + \frac{0.122}{1.122} \times 300 = 53.47 + 32.62$$

$$= 86.09°K$$

Now $\frac{G}{T} = 40$ dB/K

or G (in dB) − 10 log T = 40

or $\log T = \frac{64.5 - 40}{10} = 2.45 \qquad T = 281.83°K$

Therefore, $T_e = 281.83 - 86.09$

$= 195.74°K$

Problem - 51 :

Fig. 20.22 shows a cascaded arrangement of two 3 dB couplers used to combine three carriers at frequencies f_1, f_2 and f_3. Determine the output powers of the three carriers if the input powers for the three carriers are 50 dB (at f_1), 40dB (at f_2) and 25 dB (at f_3).

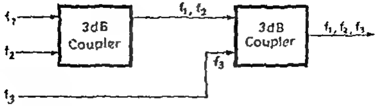


Fig. 20.22

Solution :

In the first 3dB coupler, both (f_1) and (f_2) suffer 3 dB carrier power loss.

Therefore, the carrier powers at (f_1) and (f_2) at the input of second 3 dB coupler are respectively 47dB and 37dB.

Carrier power at (f_3) at the input of second 3 dB coupler = 25 dB

Therefore, carrier power at (f_1) at the output = 47 − 3 = 44 dB

carrier power at (f_2) at the output = 37 − 3 = 34 dB

and carrier power at (f_3) at the output = 25 − 3 = 22 dB

Problem - 52 :

Refer to the coupler arrangement of Fig. 20.23. Determine the power loss suffered by each one of the five carriers after all have combined and appeared at the output.

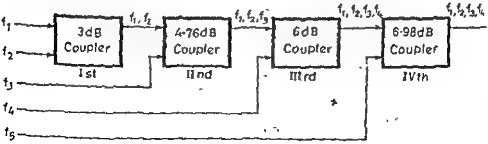


Fig 20.23

Solution :

In these directional couplers, one of the inputs suffers a power loss equal to the designated figure, 3 dB, 4.77 dB, 6 dB or 6.97 dB

as the case may be. The other input or inputs suffer a power loss that is given by :

$$-10 \log \beta^2 \text{ where } \beta^2 = (1-\alpha^2)$$

$$\text{and } \alpha^2 = \text{Log}^{-1}\left[\frac{-\text{designated figure}}{10}\right]$$

We will now analyse different couplers one at a time.

First directional coupler (3 dB coupler): Let us say (f_2) suffers a 3 dB loss, then the loss suffered by (f_1) will be :

$$-10 \log\left[1 - \log^{-1}\left\{\frac{-\text{designated figure}}{10}\right\}\right]$$

$$= -\log\left[1 - \log^{-1}(-0.3)\right]$$

$$= -10 \log (1 - 0.5)$$

$$= -10 \log (0.5) = -10(-0.3) = 3 \text{ dB}$$

Thus, both (f_1) and (f_2) have suffered a power loss of 3 dB each when they reach the input of second coupler.

Now (f_3) while combining with (f_1) and (f_2) in the second coupler suffers a 4.76 dB loss. (f_1) and (f_2) will suffer a further loss of

$$-10 \log\left[1 - \log^{-1}\left\{\frac{-4.76}{10}\right\}\right]$$

$$= -10 \log\left[1 - \log^{-1}(-0.476)\right]$$

$$= -10 \log (1 - 0.333)$$

$$= -10 \log 0.666 = 1.76 \text{ dB}$$

Thus, at the output of second coupler, (f_1) and (f_2) have suffered a loss of (3 + 1.76) = 4.76 dB each. (f_3) has also suffered a loss of 4.76 dB.

Now (f_1), (f_2) and (f_3) will suffer a loss in the third coupler equal to

$$-10 \log\left[1 - \log^{-1}\left\{\frac{-6}{10}\right\}\right]$$

$$= -10 \log\left[1 - \log^{-1}(-0.6)\right]$$

$$= -10 \log (1 - 0.25) = -10 \log 0.75 = 1.24 \text{ dB}$$

Therefore, upto the third coupler output, (f_1), (f_2) and (f_3) would have suffered a loss of (4.76 + 1.24) = 6 dB each. (f_4) has also suffered a loss of 6 dB.

While passing through fourth coupler, (f_1), (f_2), (f_3) and (f_4) will suffer an additional loss equal to :

$$-10\log\left[1-\log^{-1}\left\{\frac{-6.97}{10}\right\}\right]$$

$$=-10\log\left[1-\log^{-1}(-0.697)\right]$$

$$=-10\log(1-0.2)$$

$$=-10\log 0.8=0.98\text{ dB}$$

At the final output, therefore, (f_1), (f_2), (f_3), (f_4) have suffered a loss of $(6+0.98)=6.98$ dB each. Also, (f_5) in fourth coupler suffers a loss of 6.97 dB. Thus, at the end, all carriers have suffered a loss of 6.98 dB in the process of combining.

Problem - 53 :

In a certain satellite communication link, the uplink carrier-to-noise ratio $(C/N)_u$ is 25 dB whereas the downlink carrier-to-noise ratio $(C/N)_d$ is 20 dB. Find the link carrier-to-noise ratio (C/N).

Solution :

The link carrier-to-noise ratio (C/N) is given by

$$\frac{C}{N}=\left[\left(\frac{C}{N}\right)_u^{-1}+\left(\frac{C}{N}\right)_d^{-1}\right]^{-1}$$

$$\left(\frac{C}{N}\right)_u=25\text{ dB}=\log^{-1}\left(\frac{25}{10}\right)=316.22$$

$$\left(\frac{C}{N}\right)_d=20\text{ dB}=\log^{-1}\left(\frac{20}{10}\right)=100$$

$$\text{Therefore, }\frac{C}{N}=\left(\frac{1}{316.22}+\frac{1}{100}\right)^{-1}=\left(\frac{416.22}{31622}\right)^{-1}$$

$$=76=18.8\text{ dB}$$

Problem - 54 :

The system parameters of Ku-band (14/12 GHz) satellite link are as follows :

(I) Satellite Parameters :

Antenna gain-to-noise temperature ratio = 1.6 dB/K

Satellite saturation EIRP = 44 dBW

$= \text{EIRP (in dB)} + BO_i \text{ (in (dB)}$

$= \text{Carrier power (in dB)} + \text{Transmit antenna gain (in dB)} + BO_i \text{ (in dB)}$

$= 10 \log 200 + 57.6 + 0 = 23 + 57.6 = 80.6 \text{ dBW}$

$K = 1.38 \times 10^{-23}\ \text{J/K} = 10(\log 1.38 - 23 \log 10)$
$= -228.6 \text{ dBW/K–Hz}$

$B = 36 \text{ MHz} = 10 \log 36 \times 10^6 = 75.6 \text{ dB–Hz}$

$L = 1.5 \text{ dB}$

Substituting the values,

$$\left(\frac{C}{N}\right)_u = 80.6 - 20 \log\left(\frac{4 \times 3.14 \times 14 \times 10^9 \times 37000 \times 10^3}{3 \times 10^8}\right) + 1.6$$
$$- (-228.6) - 75.6 - 0 - 1.5$$
$$= 80.6 - 206.7 + 1.6 + 228.6 - 75.6 - 1.5$$
$$= 27\text{dB}$$

$\left(\frac{C}{N}\right)_d$ is given by :

$$EIRP_s \text{ (sat) (in dBW)} - 20 \log\left(\frac{4 \pi f_d d_d}{c}\right) + \frac{G}{T} \text{ (in dB/K)}$$
$$- 10 \log K - 10 \log B - BO_0 \text{ (in dB)} - L' \text{ (dB)}$$

where $EIRP_s$ (sat) = Satellite saturation EIRP

f_d = downlink frequency

d_d = downlink slant range

$\left(\frac{G}{T}\right)$ = Earth station antenna gain to noise temperature ratio

BO_0 = Satellite TWTA output backoff

L' = Downlink antenna tracking loss + Atmospheric attenuation

Now $(G/T) = G \text{ (in dB)} - 10 \log T = 56.3 - 10 \log 160$
$= 56.3 - 22 = 34.3 \text{ dB/}K$

Substituting the values,

$$\left(\frac{C}{N}\right)_d = 44 - 20 \log\left(\frac{4 \pi \times 12 \times 10^9 \times 37000 \times 10^3}{3 \times 10^8}\right) +$$

TWTA input back-off = 0 dB

TWTA output back-off = 0 dB

(II) Earth station parameters :

Tracking Loss = 1.5 dB (uplink) and 1 dB (downlink)

Transmit antenna gain = 57.6 dB

Receive antenna gain = 56.3 dB

Maximum uplink and downlink slant range = 37000 km

System noise temperature = 160°K

Carrier Power into antenna = 200 W

(III) Noise bandwidth = 36 MHz, Boltzmann's constant, $K = 1.38 \times 10^{-23}\ J/K$

Determine $\left(\frac{C}{N}\right)_u, \left(\frac{C}{N}\right)_d$ *and* $\left(\frac{C}{N}\right)$

Solution :

$\left(\frac{C}{N}\right)_u$ is given by .

$$\left(\frac{C}{N}\right)_u = (EIRP)_{sat} \times \left(\frac{c}{4\,\pi f_u\, d_u}\right)^2 \times \left(\frac{G_u}{T_u}\right) \times \left(\frac{1}{KB}\right) BO_i^{-1} \times L^{-1}$$

$$= (EIRP)_{sat}\ (\text{in dBW}) - 20 \log\left(\frac{4\,\pi f_u\, d_u}{c}\right) + \left(\frac{G_u}{T_u}\right)(\text{in } dB/K)$$

$$- 10 \log K - 10 \log B - BO_i\ (\text{in dB}) - L(\text{in dB})$$

where

$(EIRP)_{sat}$ = Carrier EIRP required to saturate satellite TWTA

f_u = uplink frequency

d_u = uplink slant range

(G_u/T_u) = Satellite antenna gain to noise temperature ratio

K = Boltzmann's constant

B = Noise bandwidth

BO_i = Input backoff of TWTA

L = Sum of antenna tracking loss and atmospheric attenuation

$(EIRP)_{sat}$ = EIRP × BO_i

$= \text{EIRP (in dB)} + BO_1 \text{ (in (dB)}$

$= \text{Carrier power (in dB)} + \text{Transmit antenna gain (in dB)} + BO_1 \text{ (in dB)}$

$= 10 \log 200 + 57.6 + 0 = 23 + 57\ 6 = 80.6 \text{ dBW}$

$K = 1.38 \times 10^{-23} \text{ J/K} = 10(\log 1.38 - 23 \log 10)$
$= -228.6 \text{ dBW/K-Hz}$

$B = 36 \text{ MHz} = 10 \log 36 \times 10^6 = 75.6 \text{ dB-Hz}$

$L = 1\ 5 \text{ dB}$

Substituting the values,

$$\left(\frac{C}{N}\right)_u = 80.6 - 20 \log\left(\frac{4 \times 3.14 \times 14 \times 10^9 \times 37000 \times 10^3}{3 \times 10^8}\right) + 1.6$$

$$-(-228.6) - 75.6 - 0 - 1.5$$

$$= 80.6 - 206\ 7 + 1.6 + 228.6 - 75.6 - 1.5$$

$$= 27\text{dB}$$

$\left(\frac{C}{N}\right)_d$ is given by :

$$EIRP_s \text{ (sat) (in dBW)} - 20 \log\left(\frac{4\pi f_d d_d}{c}\right) + \frac{G}{T} \text{ (in dB/K)}$$

$$- 10 \log K - 10 \log B - BO_0 \text{ (in dB)} - L' \text{ (dB)}$$

where $EIRP_s$ (sat) = Satellite saturation EIRP

f_d = downlink frequency

d_d = downlink slant range

$\left(\frac{G}{T}\right)$ = Earth station antenna gain to noise temperature ratio

BO_0 = Satellite TWTA output backoff

L' = Downlink antenna tracking loss + Atmospheric attenuation

Now $(G/T) = G \text{ (in dB)} - 10 \log T = 56.3 - 10 \log 160$
$= 56.3 - 22 = 34.3 \text{ dB}/K$

Substituting the values,

$$\left(\frac{C}{N}\right)_d = 44 - 20 \log\left(\frac{4\pi \times 12 \times 10^9 \times 37000 \times 10^3}{3 \times 10^8}\right) +$$

$$34.3 - (-228.6) - 75.6 - 0 - 1$$

$$= 44 - 205.4 + 34.3 + 228.6 - 75.6 - 1$$

$$= 24.9 \text{ dB}$$

Now $\left(\frac{C}{N}\right)_u = 27 \text{ dB} = 501.2$

$\left(\frac{C}{N}\right)_d = 24.9 \text{ dB} = 309$

Therefore $\left(\frac{C}{N}\right) = \frac{501.2 \times 309}{501.2 + 309} = 191.15 = 22.8 \text{ dB}$

Problem - 55 :

The carrier power to the earth station transmit antenna is 500 watts. If the satellite TWTA's input back-off is 1 dB, determine the carrier EIRP required to saturate the satellite TWTA if the transmit antenna gain is 60 dB.

Solution :

The input back off (BO_i) is given by :

$$BO_i = \frac{EIRP\,(\text{sat})}{EIRP}$$

or BO_i (in dB) = $EIRP$ (*sat*) (in dBW) – $EIRP$ (in dBW)

Now $EIRP = P_T G_T = 10 \log 500 + 60 = 87$ dBW

Therefore, $EIRP$(sat) = $EIRP$ (in dBW) + BO_i (in dB)

$$= 87 + 1 = 88 \text{ dBW}$$

Problem - 56 :

In a satellite link, the satellite saturation EIRP is 50 dBW. If the satellite TWTA output back off is 2, determine the satellite EIRP for the retransmitted carrier.

Solution :

Satellite TWTA output back-off, $BO_0 = \frac{EIRP_s\,(\text{sat})}{EIRP_s}$

where $EIRP_s$ (sat) = satellite saturation EIRP

and $EIRP_s$ = satellite EIRP for retransmitted carrier

$EIRP_s$ (in dB) = $EIRP_s$ (sat) in dB – BO_0 (in dB)

$BO_0 = 2 = 10 \log 2 = 3\text{dB}$

Therefore *EIRPs* (in dB) $= 50 - 3 = 47$ dBW

Problem - 57 :

Two geostationary satellites A and B in the same orbit of 42164 Km radius are stationed at 85°W and 25°W longitudes. The two satellites have a slant range of 38000 km and 36000 km from a common earth station respectively. Determine the angular separation of the two satellites as viewed by the earth station Also determine the separation distance between the two satellites in the orbit.

Solution :

Refer to Fig. 20.24

If (d) is the separation distance between the satellites A and B, then

$$d^2 = d_A^2 + d_B^2 - 2d_A d_B \cos\theta$$

Also $$d^2 = r^2 + r^2 - 2r^2 \cos\beta$$

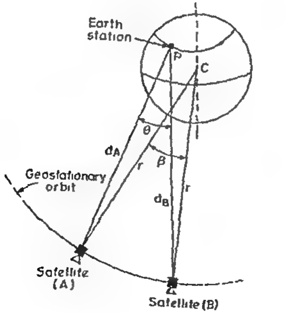


Fig. 20.24

Therefore, $d_A^2 + d_B^2 - 2d_A d_B \cos\theta = 2r^2(1 - \cos\beta)$

or $\quad \theta = \cos^{-1}\left[\frac{d_A^2 + d_B^2 - 2r^2(1-\cos\beta)}{2\,d_A d_B}\right]$

θ = angular separation between satellites A and B as viewed from earth station

β = angular separation between two satellites
$= 85^\circ - 25^\circ = 60^\circ$

r = geostationary orbit radius = 42164 km

$$\theta = \cos^{-1}\left[\frac{(38000)^2 + (36000)^2 - 2\times(42164)^2(1-\cos 60^\circ)}{2\times 38000\times 36000}\right]$$

$$= \cos^{-1}\left[\frac{1444\times10^6 + 1296\times10^6 - 1777.8\times10^6}{2736\times10^6}\right]$$

$$= \cos^{-1}\left[\frac{962.2}{2736}\right] = \cos^{-1} 0.3516 = 69.4^\circ$$

The separation distance (d) can be computed from

$$d = \sqrt{2\,r^2(1-\cos\beta)}$$

$$= 1.414\, r\sqrt{(1-\cos\beta)}$$

$$= 1.414\times 42164\sqrt{1-\cos 60^\circ}$$

$$= 42164 \text{ km}$$

Problem - 58 :

For the situation depicted in Problem - 57, if the satellites A and B were located at 25°W and 30°W respectively, determine angular separation (θ) and separation distance (d).

Solution :

The angular separation (θ) is given by .

$$\theta = \cos^{-1}\left[\frac{(38000)^2 + (36000)^2 - 2(42164)^2(1-\cos 5^\circ)}{2\times 38000\times 36000}\right] \quad ..\beta = 5^\circ$$

$$= \cos^{-1}\left[\frac{1444\times10^6 + 1296\times10^6 - 1777.8\times10^6\times 7.6\times10^{-3}}{2736\times10^6}\right]$$

$$= \cos^{-1}\left(\frac{1444 + 1296 - 13\ 5}{2736}\right) = \cos^{-1}(0.9965) = 4\ 77^\circ$$

The separation distance (d) is given by :

$$d = 1.414\, r\sqrt{1-\cos\beta}$$

$= 1.414 \times 42164 \sqrt{1 - \cos 5^\circ}$

$= 1.414 \times 42164 \sqrt{1 - 0.996}$

$= 1.414 \times 42164 \times 0.063 = 3756\text{km}$

Problem - 59 :

A geostationary satellite is located at 100°W longitude. Calculate the power flux density at the satellite for an earth station located at 90°W longitude and 40°N latitude given that

Earth station antenna diameter = 5 m

Antenna efficiency = 0.55

Carrier frequency = 14 GHz

Earth station power amplifier saturation power = 500 W

Power amplifier output back-off = 3 dB

Waveguide loss between amplifier output and antenna input = 0.5 dB

Orbital radius = 42164 Km and Earth's radius = 6378 km.

Solution :

$$\text{Antenna gain, } G = \eta \frac{4 \pi A f^2}{c^2}$$

$$= \eta \left(\frac{\pi f D}{c}\right)^2$$

$$= 0.55 \left(\frac{\pi \times 14 \times 10^9 \times 5}{3 \times 10^8}\right)^2$$

$$= 295240 = 54.7 \text{ dB}$$

Earth station power amplifier saturation power = 500 watts

= 26.98 dB

Power amplifier output back-off = 3 dB

Therefore, operating power = 26.98 – 3 = 23 98 dB

Waveguide loss = 0.5 dB

Therefore, power fed to antenna input = 23.98 – 0 5

= 23.48 dB

$EIRP = 23\ 48 + 54\ 7$

$= 78.18 \text{ dB} = 65765784$

The power flux density at the satellite is given by

$$\left(\frac{EIRP}{4\pi d^2}\right)$$

where d = slant range from satellite to earth station

$$d^2 = R^2 + r^2 - 2Rr \sin\left[E + \sin^{-1}\left(\frac{r}{R}\cos E\right)\right]$$

where R = orbital radius

r = earth's radius

E = angle of elevation

Also, $E = \tan^{-1}\left[\frac{R - r\cos\theta_l \cos|\theta_s - \theta_L|}{r \sin\{\cos^{-1}(\cos\theta_l \cos|\theta_s - \theta_L|)\}}\right]$

$$- \cos^{-1}(\cos\theta_l \cos|\theta_s - \theta_L|)$$

$$= \tan^{-1}\left[\frac{42164 - 6378\cos 40^\circ \cos 10^\circ}{6378 \sin\{\cos^{-1}(\cos 40^\circ \cos 10^\circ)\}}\right] - \cos^{-1}(\cos 40^\circ \cos 10^\circ)$$

$$= \tan^{-1}\left[\frac{42164 - 6378 \times 0.754}{6378 \sin(\cos^{-1} 0.754)}\right] - \cos^{-1} 0.754$$

$$= \tan^{-1}\left(\frac{37355}{4184}\right) - 41^\circ$$

$$= 83.6^\circ - 41^\circ = 42.6^\circ$$

Therefore, $d^2 = (42164)^2 + (6378)^2 - 2 \times 42164 \times 6378 \times$

$$\sin\left[41^\circ + \sin^{-1} \frac{6378}{42164} \cos 41^\circ\right]$$

$$= 1777802896 + 40678884 - 537843984 \sin[41^\circ + 6.55^\circ]$$

$$= 1777802896 + 40678884 - 537843984 \times 0.7378$$

$$= 1777802896 + 40678884 - 396821291$$

$$= 1421660489$$

$$d = \sqrt{1421660489} = 37705 \text{ km}$$

The power flux density at the satellite $= \dfrac{EIRP}{4\pi(37705 \times 10^3)^2}$

$$= \frac{65765784}{12.56 \times 1421667025 \times 10^6}$$

$= 3.68 \times 10^{-9}\ W/m^2$

$= -84.34\ dBW/m^2$

Problem - 60 :

Determine the theoretical maximum area of the earth's surface that would be in view from a geostationary satellite at a height of 35786 Km from earth's surface. Also determine the area in view for a minimum elevation angle of 10°. (Assume earth's radius = 6378 km)

Solution :

Refer to Fig. 20.25. For theoretical maximum coverage, elevation angle, E = 0°.

Therefore, $\alpha = \sin^{-1}\left(\frac{R_e}{R_e + H}\right)$

where R_e = earth's radius

H = height of satellite above earth's surface

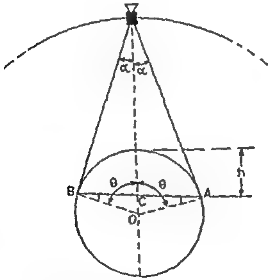


Fig. 20.25

$$\alpha = \sin^{-1}\left(\frac{6378}{6378 + 35786}\right) = 8.7^\circ$$

$\theta = 90^\circ - \alpha - E = 90^\circ - 8.7^\circ = 81.3^\circ$

In the right angle triangle AOC,

$OC = OA \sin 8.7^\circ$ ....$\angle OAC = 8.7^\circ$

$= 6378 \sin 8.7^\circ$

$= 964.74$ km

Therefore, distance (h) = 6378 − 964.74 = 5413.26 km from geometry, surface area of the shaded region is given by :

$$2\pi R_e h$$

$$= 2\pi \times 6378 \times 5413.26$$

$$= 216821850 \text{ km}^2$$

For $E = 10°$, $\alpha = \sin^{-1}\left(\frac{6378}{6378 + 42164}\cos 10°\right) = 8.56°$

$\theta = 90 - \alpha - E = 90 - 8.56 - 10 = 71.44°$

The new value of OC = 6378 sin 18.56° ≈ 2030 km

The new value of $(h) = 6378 - 2030 = 4348$ km

Therefore covered area $= 2\pi \times 6378 \times 4348$

$$= 174154096 \text{ km}^2$$

Problem - 61 :

Determine the percentage of earth's area covered for the two cases of angle of elevation in Problem - 60. how many geostationary satellites, you think, would be required for global coverage ?

Solution :

Percentage of earth's surface area covered $= \frac{2\pi R_e h}{4\pi R_e^2} \times 100$

$$= \frac{h}{2R_e} \times 100$$

For $E = 0°$, $h = 5413.26$ km

Percentage of area covered $= \frac{5413.26}{2 \times 6378} \times 100 = 42.4\%$

For $E = 10°$, $h = 4348$ km

Percentage of earth's surface area covered $= \frac{4348}{2 \times 6378} \times 100$

$$= 34\%$$

Three geostationary satellites would be required for global coverage provided that minimum elevation angle requirement for the earth stations does not exceed 10°.

Problem - 62 :

A geostationary satellite is equipped with both a spot beam antenna with a covering angle of 4.5° and a global coverage antenna

with a beam angle of 17.34°. Determine the gain of spot beam antenna if the global coverage antenna has a gain of 50 dB.

Solution :

The square of the beam angle is roughly inversely proportional to the gain of the antenna.

Gain of global coverage antenna = 50 dB = 100000

Therefore, gain of spot beam antenna = $100000 \times \left(\frac{17.34}{4.5}\right)^2$

$= 14.85 \times 10^5$

$= 61.7$ dB

TWENTY ONE

Illustrated Glossary of Satellite Relevant Terms and Definitions

Antenna Gain (Fig. 21.1) : It is a measure of the directionality of the antenna or its capability to concentrate power in a preferred direction. It is directly proportional to the aperture area of the antenna and the square of the transmission frequency. A given antenna transmits and receives with the same gain. Also, the antenna beam angle when squared is roughly inversely proportional to the aperture which enables a comparison of the gains of the antennas on the basis of the beam angles. For instance, a spot beam antenna with a covering angle of 4.5° would have a gain that would be $(17.34/4.5)^2 = 14.85$ times the gain of a global coverage antenna with a 17.34° beam angle.

$$G = \frac{4\pi A}{\lambda^2}$$

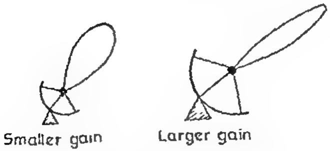


Fig. 21.1

Apogee (Fig. 21.2) : Apogee is that point in the satellite orbit that is the farthest from the center of the earth. It would be relevant only in case of an elliptical orbit. With reference to the ellipti-

cal orbit shown in Fig. 21.2, if (a) is the semi-major axis of the ellipse, then the apogee distance (distance of apogee point from center of earth) is given by a× (1+e) where (e) is the orbit eccentricity. Also, the *satellite velocity is the lowest at the apogee* point.

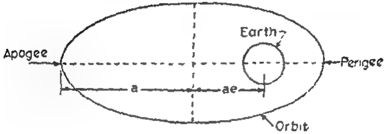


Fig. 21.2

Arianespace : Arianespace is the name of the company established for the purpose of producing, financing and marketing European Space Agency's (ESA) launch vehicle.

Artificial Gravity : Use of centrifugal force to simulate weight reaction in a condition of free fall. It may be achieved by spinning the vehicle to make the centrifugal force of outer periphery, or bodies within the vehicle to replace the weight reaction experienced at the surface of earth.

ASAT : It is an anti-satellite satellite meant for the purpose of intercepting another satellite.

Astronautics : The science and technology of space flight.

Attitude : Attitude of a space vehicle is its orientation as determined by relationship between its axes and some reference plane.

Attitude Control System : It is the system that achieves and maintains the required attitude. The main functions of attitude control system include maintaining accurate satellite position throughout the life span of the satellite, controlling satellite

manoeuvres while in the transfer orbit and also during stationkeeping. The requirements of attitude control system mainly depend on whether the satellite is spin stabilised or three-axis stabilised.

AWGN : AWGN stands for Additive White Gaussian Noise.

Azimuth Angle : It is defined as the angle produced by intersection of local horizontal plane and the plane passing through the earth station, the satellite and center of earth. Depending upon the location of the earth station and the subsatellite point (point of intersection of line joining satellite and center of earth and equator), the azimuth angle (A) can be computed as follows :

For earth station in northern hemisphere,

$A = 180° - A'$ . . Earth station west of satellite

$A = 180° + A'$ ... Earth station east of satellite

For earth station in, southern hemisphere,

$A = A'$ .. Earth station west of satellite

$A = 360° - A'$ ... Earth station east of satellite

$$A' = \tan^{-1}\left[\frac{\tan | \theta_S - \theta_L |}{\sin \theta_l}\right]$$

where θ_S = satellite longitude

θ_L = earth station longitude

θ_l = earth station latitude

Blackout (Radio) : A temporary loss of radio communication between a spacecraft re-entering the atmosphere and the ground stations due to an ionised sheath of plasma that develops around the vehicle.

Booster : The first stage of a missile or a rocket

Centrifugal Force (Fig. 21.3) : A force that is directed away from the center of rotation. A satellite orbitting around earth with center of earth as its center of rotation is always acted upon by a centrifugal force ($= mV^2/R$) acting in a direction away from the center of earth as shown in Fig. 21.3. Here (m) is mass of satellite, (R) is its orbital radius and (V) is the orbital velocity.

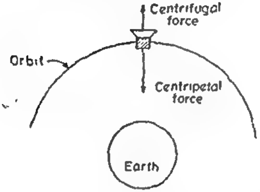


Fig. 21.3

Centripetal Force (Fig. 21.3) : A force that is directed towards the center of rotation. A satellite orbitting earth is always acted upon by a centripetal force directed towards the center of earth due to gravitational attraction. The magnitude of this centripetal force is given by :

$$\frac{G\,Mm}{R^2}$$

Here (G) is earth's gravitation constant, (M) is mass of earth, (m) is mass of satellite and (R) is orbital radius. The centrifugal force acting outwards counterbalances the centripetal force acting inwards as shown in Fig. 21.3 and this keeps the satellite in orbit. Infact, a satellite would move in a circular orbit around earth at a given height only with a velocity that makes the centrifugal force counterbalance the centripetal force.

Countdown : A count in inverse numerical order in hours, minutes and finally in seconds, of the time

remaining before the launch of a rocket. The final preparations, such as checking various systems and subsystems, are done during this period. In general, countdown refers to a series of events leading to a climatic finish, each event in the series being in accordance with a schedule in which time is counted backwards towards zero, the finishing point.

Demand Assignment Multiple Access (DAMA) : While the conventional Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Single Channel Per Carrier (SCPC) multiple access techniques, in their basic form, allocate fixed amounts of capacity to users, the use of DAMA technique enables the allocated capacities to be varied dynamically according to individual demands. Demand assignment is used in conjunction with SCPC and TDMA systems.

Diplexer : Diplexer is a three port filter device that allows two receivers or transmitters to be connected to a single antenna without undesired interaction. In should not be confused with a Duplexer which is a device that allows to use the same antenna for both transmission as well as reception.

Doppler Effect : Doppler effect is the apparent change in frequency due to relative motion of the source and the observer. The change in frequency due to doppler effect is given by:

$$\pm\left(\frac{2\,v_r}{\lambda}\right)$$

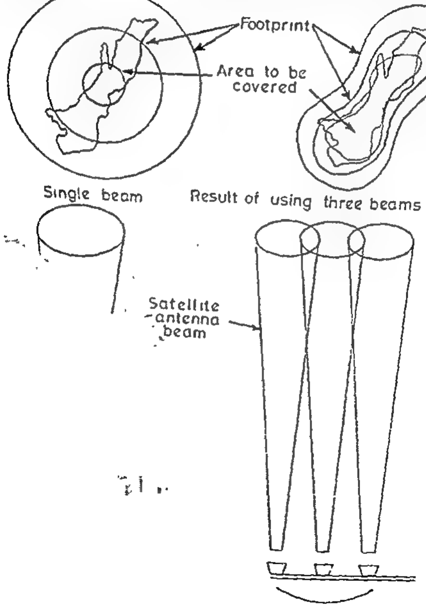
where (θ_r) is the relative velocity and (λ) is the wavelength. The frequency increases when the two are [illegible] towards each other and decreases [illegible] are moving [illegible] each [illegible]

Down Converter : [illegible] modu- [illegible] and [illegible] F in [illegible] the [illegible] is [illegible]

where $\mu = G.M$ (G being earth's gravitation constant and M being its mass) and (R) is the distance of the vehicle from center of earth. This figure is 11.6 Km/s for bodies trying escape from the surface of earth

Exhaust Velocity : The velocity of the exhaust leaving the nozzle of a rocket motor

Foot print (Fig. 21.6) : It is the earth's surface area illuminated by the satellite antenna. Its shape and size



Equatorial Orbit (Fig. 21.5) : An orbit in the plane of equator.

Equinox (Fig. 21.4) : It is the point of time when the sun crosses the equator making the lengths of day and night equal. We have the autumn equinox occuring on September 21 and spring equinox according on March 21. Equinoxes are relevant to communication satellites as the eclipse duration is the maximum at the equinoxes. Fig. 21.4 shows the shadow angle at an equinox. The eclipse duration here is the time taken by the satellite to move from point A to B For a geostationary satellite, the eclipse duration at equinox is about 1.20 hours

Equivalent Isotropic Radiated Power (EIRP) : It is a measure of radiated or transmitted power of an antenna. It can be computed from the antenna gain and the power fed to the antenna input. That is, EIRP = $P_t G_t$ or EIRP (in dBW) = P_t (in dBW) + G_t (in dB). In simple words, EIRP is the transmitter power which would be required to be fed to an isotropic antenna to give the same result as the transmitter and the antenna under consideration. Although, the EIRP is defined and measured at the transmitter antenna, its practical significance is at the receiving end of the link. EIRP of the earth station transmitting antenna can for instance be used to compute the power received by the satellite under a variety of transmission path conditions. Similarly, EIRP of satellite's transmitting antenna can be used to compute power received at the earth station

Escape Velocity : Escape velocity is the minimum velocity away from a parent body that a particle or another body must acquire to escape permanently from the gravitational attraction of the parent. In case of launching of satellites or rockets, the vehicle has to escape from the gravitational attraction of the earth. It can be computed from $\sqrt{2\mu/R}$

where $\mu = G.M$ (G being earth's gravitation constant and M being its mass) and (R) is the distance of the vehicle from center of earth. This figure is 11.6 Km/s for bodies trying escape from the surface of earth

Exhaust Velocity : The velocity of the exhaust leaving the nozzle of a rocket motor

Foot print (Fig. 21.6) : It is the earth's surface area illuminated by the satellite antenna. Its shape and size

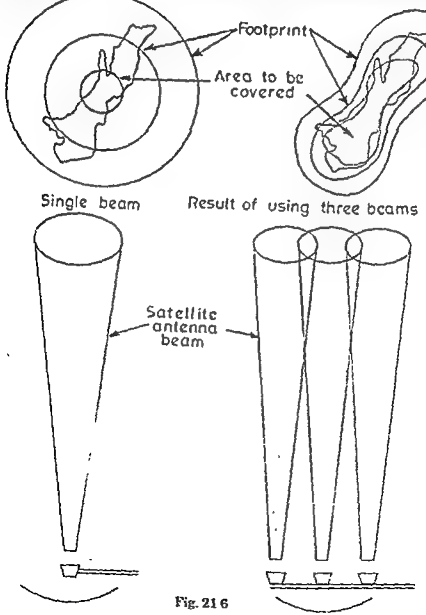


Fig. 21 6

depend upon a number of factors including antenna design and angle of elevation.

Technically speaking, footprint is used to describe equipower flux contours provided by a satellite transmitting antenna. Footprints are usually drawn for either equal power flux density (dBW/m^2) or EIRP (dB) The size and shape of footprint are important from the viewpoint of size and shape of the territory the transponder is to serve. For instance, a circular beam would not serve any useful purpose while illuminating territories such as that of Japan. Fig. 21 6 shows the use of multiple feeds to shape the beam and hence the footprint.

Free Fall : Free fall is the ideal falling motion of a body acted upon by the pull of earth's gravitational field

Frequency Division Multiple Access (FDMA) Fig. 21.7) : It is the earliest and still the commonest form of all the multiple access techniques of satellite communications. Each of the earth stations within the satellite's footprint transmits one or more carriers at different center frequencies. Each carrier is assigned a frequency band with a small gaurd band to avoid overlapping between adjacent carriers. The satellite transponder receives all the carriers within its bandwidth, does the necessary translation and amplification and retransmits them back to earth. The different earth stations are capable of selecting the carriers containing messages of their interest. Two FDMA techniques are in operation today. One is multichannel per carrier where the earth station frequency [illegible]

In the other technique called Single Channel Per Carrier (SCPC), each channel modu-

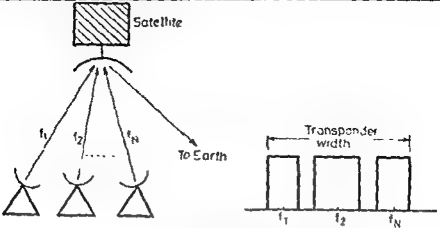


Fig. 21.7

lates a separate RF carrier and is transmitted to FDMA transponder

Geodesy : The science of earth's shape

Geostationary Orbit (Fig. 21.8) : It is an equatorial circular orbit at such a height from earth's surface that a satellite moving from west to east has a velocity so as to orbit the earth once in a time equal to the time taken by earth to complete one rotation around its axis. This time is about 24 hours. In such a case, the satellite appears stationary to an observer on earth. The orbital radius of a geostationary satellite tunes out to be 42164.2 Km. The movement of the satellite is thus in synchronism with earth's rotation. All geostationary satellites are geosynchronous but the reverse is not true. It is also known as a Clarke's orbit.

Global Positioning System (GPS) : GPS is a positioning and navigation system designed to use some 18 to 24 satellites, each carrying atomic clocks, to provide a receiver anywhere on earth with extremely accurate measurement of its three dimensional position, velocity and time.

GTO : Geostationary transfer orbit

Inclination (Fig. 21.9) : The angle between the orbital plane and equatorial plane.

Inertial Guidance : Inertial guidance is an on-board system for launch vehicles and spacecraft where the

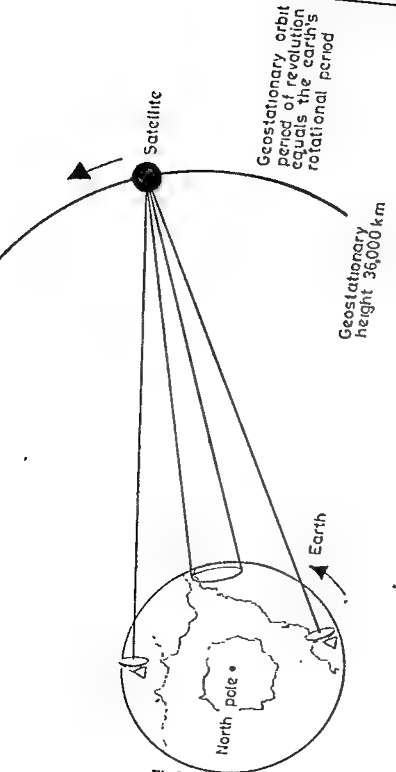

Geostationary orbit
period of revolution
equals the earth's
rotational period
Satellite
Geostationary
height 36,000 km
Earth
North pole

Fig 21.8

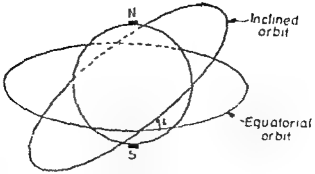


Fig. 21.9

gyros, accelerometers and other devices meet the guidance requirement. More precisely, it is a self contained navigation system which basically comprises of accelerometers mounted on a gyrostabilised platform. An accelerometer is required for each direction of possible motion. The accelerometer output can be integrated twice to determine position. The gyros can be used to provide information about the orientation of the vehicle.

Launch Complex : The complex of site facilities and equipment used to launch a missile or a space vehicle.

Launch Pad : Launch pad is the load bearing base from where a rocket or a spacecraft positioned on its launcher is fired.

Launch Window : Launch window is the time interval during which a space vehicle can be launched to accomplish a given mission.

Lift-off : Lift-off marks the start of a rocket's flight from its launch pad.

Mach Number : The ratio of the speed of a vehicle (or of a liquid or gas) to the speed of sound.

Magnetic storm : A disturbance of the earth's magnetic field initiated by a solar flare or sun spot.

Magnetosphere : The region of space surrounding earth which is dominated by magnetic field.

Molniya Orbit (Fig. 21.10) : It is a highly inclined, highly eccentric, elliptical orbit with an orbital period of about 12 hours and is popular with some of the

Russian communication satellites. Molniya orbit serves the purpose of a geosynchronous orbit for high latitude regions. The satellite in this orbit spends about 8 hours above a particular high attitude station before diving down to a low level perigee at an equally high southern latitude. Usually, three satellites at different phases of same Molniya orbit are capable of providing uninterrupted service.

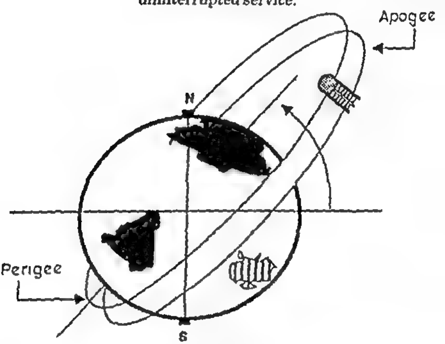


Fig 21.10

Orbit : *The path of a body acted upon by the force of gravity. The word orbit is usually associated with the continuous path of a body which does not impact with its primary.*

Orbital Period : *The time taken to complete one orbit. The orbital period of a circular satellite orbit with a radius (R) is given by*

$$\frac{2\pi R^{3/2}}{\sqrt{GM}}$$

The orbital period of an elliptical satellite orbit with its semi-major axis equal to (a) is given by

$$2\pi \sqrt{a^3/GM}$$

Orbital Velocity : The velocity necessary to overcome the gravitational attraction of earth so as to keep the satellite in orbit. The orbital velocity in a circular orbit of radius (R) is given by:

$$\sqrt{GM/R}$$

The orbital velocity at any point distance (r) from the center of earth in ar elliptical orbit with a semi-major axis equal to (a) is given by :

$$\sqrt{GM\left[\left(\frac{2}{r}\right)-\left(\frac{1}{a}\right)\right]}.$$

Parking Orbit (Fig. 21.11) : Parking orbit is a temporary earth orbit during which the space vehicle is checked out and its trajectory carefully measured to determine the amount and time of increase in velocity required to send it into a final orbit or into space in the desired direction

Payload : Payload is the useful cargo of a space vehicle A rocket's payload may be a com-

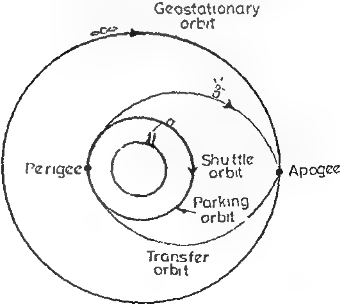


Fig. 21.11

munications satellite and a satellite's payload may be a transponder.

Perigee : Perigee is the point in the orbit that is nearest to the earth. (Fig. 21.2). It would be relevant only in case of an elliptical orbit. With reference to the elliptical orbit shown in Fig. 21.2, if (a) is the semi-major axis of the ellipse, then the perigee distance (distance of perigee point from center of earth) is given by a $(1 - e)$ where (e) is the orbit *eccentricity*.

Pitch : Movement of a spacecraft about an axis which is perpendicular to its longitudinal axis. It is the degree of elevation or depression.

Polar Orbit (Fig. 21.12) : An orbit which passes over the poles. Polar orbits are relevant for those countries which are located near the poles.

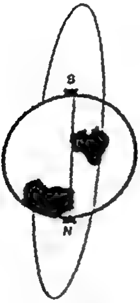


Fig. 21.12

Primary : The body around which a satellite orbits. Earth is the primary for artificial satellites.

Project Irridium (Fig. 21.13) : Project Irridium is a global communication system conceived by Motorola that will make use of satellites placed in lower earth orbits. A total of 77 satellites are arranged in a distributed architecture with each satellite carrying (1/77) of the total system capacity. The system is intended to a provide a variety of telecom services on the global level. The project is so named because Irridium's atomic number is 77.

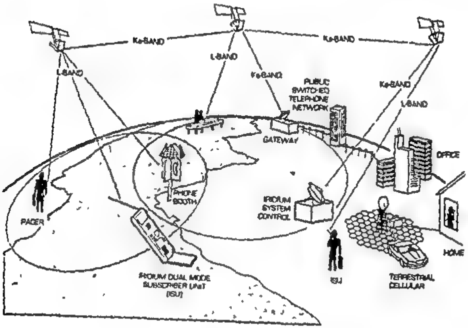


Fig. 21.13

Propellent : A solid or liquid substance burnt in a rocket for the purpose of producing thrust.

Radio Telescope : A receiving station for detecting radio waves emitted by celestial bodies or space vehicles.

Sidereal Day : A sidereal day is defined as the time taken by the earth to rotate on its axis relative to distant stars rather than the sun. A sidereal day is measured as 23 hours, 56 minutes, 4.09 seconds.

Spin-Stabilised Satellites (Fig. 21.14) : In a spin stabilised satellite, the body of the satellite spins at about 30 to 100 rpm about the axis perpendicular to the orbital plane. Spin stabilised satellite has gyroscopic stiffness as a result of rotating or spinning about its axis of maximum moment of inertia. Spin stabilised satellites are normally dual spin satellites with a *spinning section* and a despun section on which antennas are mounted. The despun section and hence the antennas are kept stationary with respect to earth by counter rotating the despun section. Spin stabilised satellites have body mounted solar calls.

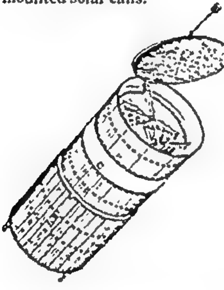


Fig. 21.14

Spot Beam : A beam generated by a communication satellite antenna of sufficient size that the [illegible] diameter is illuminated on earth

Spread Spectrum Techniques : Spread spectrum techniques are used in military communications using satellites to give them an anti jamming capability by forcing the jammer to deploy the transmitted jamming power over a much wider bandwidth than would be necessary for a conventional system. The spread spectrum

Time Division Multiple Access (TDMA) (Fig. 21.15) : Time Division Multiple Access (TDMA) is a technique in which different earth stations in the satellite's footprint making use of satellite transponder use a single carrier on a time division basis. Different earth stations transmit traffic bursts in a periodic time frame called the TDMA frame. Over the length of a burst, each earth station has the entire transponder bandwidth at its disposal. The traffic burst from different earth stations are synchronised so that all bursts arriving at the transponder are closely spaced but do not overlap. The transponder works on a burst at a time and retransmits back to the earth the sequence of bursts. All earth stations can receive the entire sequence and extract the signal of their interest.

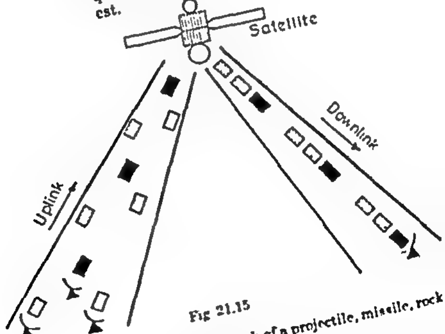


Fig 21.15

Trajectory : The flight path of a projectile, missile, rocket or satellite

Transponder : The equipment that receives a signal, processes it and then retransmits at a different frequency.

Up-Converter : The up-converter accepts the modulated IF carrier and translates its IF frequency

the up-link RF frequency in the up-link frequency spectrum of the satellite. The up-converter in a satellite link is usually accomplished in a dual conversion process.

V-SAT System : VSAT systems are usually considered to be those designed to operate with antennas that are the equivalent of 1.8 m diameter or less. The relatively low gain of VSAT has to be countered by a careful design.

Yaw : Yaw is the rotation of a vehicle about its vertical axis.

Zero 'g' : Zero 'g' is a state when the gravitational attraction is opposed by equal and opposite inertial forces and the body experiences no mechanical stress.

SELF ASSESSMENT QUESTIONS

Below are given objective type questions in the form of multichoice questions, incomplete statements and True / False statements. Each of the multichoice questions is followed by some possible answers with only one of the answers being correct. The incomplete statements are also provided with two or three possible choices with only one of them being the right one. You have to pick the right answer or the correct choice for the first two types of questions and identify true and false statements in the third category of questions

Multichoice Questions

1 One of the following laws governs the movement of artificial satellites in earth orbits.

(a) Newtonian laws of mechanics

(b) Laws of quantum mechanics

(c) Galilean laws

(d) Kepler's laws

2. If (G) is the earth's gravitational constant and (M) the mass of earth, then for a circular orbit of radius (R), the satellite's orbital velocity (V) is given by :

(a)$V = \sqrt{GM/R}$ (b)$V = \sqrt{2GM/R}$

(c) $V = \sqrt{R/GM}$ (d)$V = \sqrt{2}\ G/R$

3 In a satellite orbit around earth, the force acting outwards from the center of earth is the

(a) force of gravitation (b) centripetal force

(c) centrifugal force (d) none of these

4. One of the following satellite systems is used for intercontinental communications.

(a) DOMSAT

(b) TIROS-N

(c) INTELSAT

(d) MARISAT

5. One of the following satellite systems is used for weather forecast applications.

(a) GORIZONT

(b) TIROS-N

(c) COMSAT

(d) SPOT

6. One of the following satellite systems is used for earth's resources survey.

(a) INTELSAT

(b) SPOT

(c) EUTELSAT

(d) TIROS-N

7. One of the following satellites is not used for communication services.

(a) GORIZONT

(b) EKRAN

(c) INSAT

(d) LANDSAT

8. One of the following communication satellites is in a highly eccentric, inclined orbit.

(a) Molniya series (b) Raduga

(c) Ekran (d) Gorizont

9 With reference to satellite communication systems, doppler frequency shift is absent in one of the following satellite systems

(a) Geostationary satellite

(b) Near earth orbit satellites

(c) Domestic satellite systems

(d) Geosynchronous satellites

10. One of the following expressions can be used to compute the eccentricity (e) of an eccentric elliptical orbit with apogee and perigee distances of (r_a) and (r_p) respectively.

(d) focussed spot beams and zone beams

(e) all of above

16. Higher the frequency of satellite or earth station transmitter,

(a) higher is the potential bandwidth that can be used for communications

(b) closer the satellites can be spaced without interfering with each other

(c) narrower is the radiation beamwidth for a given earth station and satellite antenna diameter

(d) all of above

(e) none of these

17. Satellite capacity depends on

(a) weight that can be placed in orbit

(b) panel area available for energy dissipation

(c) transmitter power

(d) all of above

18. A spin stabilised satellite

(a) uses solar panels whose cells are continually oriented towards the sun

(b) uses solar cells mounted on a cylindrical body that is continually rotated so that about 40 percent of the cells receive solar radiation at a given time

uses gyroscopic action of a spinning satellite

(a) and (b)

(b) and (c)

) and (c)

satellite

panels whose cells are continually oriented e sun

cells mounted on a cylindrical body that con- that about 40 percent of the cells receive n at a given time

g satellite to maintain orientation in space

(a) $e = \frac{r_p}{r_a}$ (b) $e = \left(\frac{r_a - r_p}{r_a + r_p}\right)$

(c) $e = \left(\frac{r_a + r_p}{r_a - r_p}\right)$ (d) $e = \frac{r_a}{r_p}$

11. Satellite transponders
    (a) use a single frequency for reception and retransmission of information to and from earth
    (b) use a lower frequency for reception and a higher frequency for retransmission
    (c) use a higher frequency for reception and a lower frequency for retransmission
    (d) none of these
12. In the C-band transponders, the uplink frequency is about
    (a) 6 GHz (b) 4 GHz
    (c) 14 GHZ (d) 11 GHz
13. The down-link frequency in a C-band transponder is about
    (a) 6 GHz (b) 4 GHz
    (c) 14 GHz (d) 11 GHz
14. A geosynchronous orbit is the one when the
    (a) satellite is placed in an orbit 15,000 miles above earth's surface in a north to south orbital path
    (b) the satellite is placed 22,000 miles above earth's surface in an orbit that matches one of the longitudinal lines of earth.
    (c) The satellite is placed 35,000 miles above earth's surface in equatorial orbit.
    (d) the satellite is placed 22,000 miles above earth's surface in an orbit in equatorial plane
    (e) the satellite's orbital velocity is in synchronism with the earth's rotation
15 Satellites allow earth stations to share the satellite equipment through
    (a) Time Division Multiplexing (TDM)
    (b) Frequency Division Multiplexing (FDM)
    (c) Multiple Frequency UP and DOWN links

(d) focussed spot beams and zone beams

(e) all of above

16. Higher the frequency of satellite or earth station transmitter,

(a) higher is the potential bandwidth that can be used for communications

(b) closer the satellites can be spaced without interfering with each other

(c) narrower is the radiation beamwidth for a given earth station and satellite antenna diameter

(d) all of above

(e) none of these

17. Satellite capacity depends on

(a) weight that can be placed in orbit

(b) panel area available for energy dissipation

(c) transmitter power

(d) all of above

18. A spin stabilised satellite

(a) uses solar panels whose cells are continually oriented towards the sun

(b) uses solar cells mounted on a cylindrical body that is continually rotated so that about 40 percent of the cells receive solar radiation at a given time

(c) uses gyroscopic action of a spinning satellite

(d) both (a) and (b)

(e) both (b) and (c)

(f) both (a) and (c)

19. A body stabilised satellite

(a) uses solar panels whose cells are continually oriented towards the sun

(b) uses solar cells mounted on a cylindrical body that continually rotates so that about 40 percent of the cells receive solar radiation at a given time

(c) uses a spinning satellite to maintain orientation in space

(d) uses a spinning momentum wheel to maintain orientation is space
(e) both (a) and (c)
(f) both (b) and (d)
(g) both (a) and (d)

20. For the earth station antennas to be 6 feet in diameter, the satellite frequency bands must be in
(a) 4/6 GHz range (b) 12/14 GHz range
(c) 20/30 GHz range (d) both (a) and (b)

21 Satellites may re-use the same frequency in the same area by
(a) having many small antennas
(b) overlapping radiation zones
(c) TDMA (d) FDMA
(e) any of above (f) (c) and (d)

22. The satellite orbit almost invariably used with remote sensing satellites is the
(a) geostationary orbit (b) geosynchronous orbit
(c) sun synchronous orbit (d) Molniya orbit

23 With reference to geosynchronous and geostationary satellite orbits,
(a) the two are identical
(b) the geosynchronous satellite orbit is in the plane of the equator
(c) while geosynchronous orbits are mainly used for meteorological applications, geostationary satellite orbits are mainly used for communication applications
(d) while a geostationary orbit is in the equatorial plane, the orbital plane of a geosynchronous satellite is inclined to the equatorial plane.

24. One of the following statements is wrong
(a) The Molniya orbit is a highly eccentric, near polar orbit
(b) The true geostationary orbit is circular and is in the plane of the equator.
(c) The inclined elliptical orbit can never be used for communication purposes.

(d) The orbital plane of a satellite in sun synchronous orbit rotates in synchronism with earth's revolution around sun.

15. The location of a geostationary satellite is always given in terms of

(a) a certain longitude

(b) a certain latitude

(c) longitude and latitude

(d) distance from earth's surface

26. The orbital velocity of the satellite

(a) is directly proportional to its distance from earth's surface

(b) is inversely proportional to square root of its distance from earth's center

(c) depends upon the thrust with which it is launched

(d) is continuously changing as the satellite revolves

27. With reference to satellites, the first orbital velocity (υ_1) which is the minimum horizontal launch velocity required to put a satellite into a circular orbit around earth and second orbital velocity (υ_2) which is the horizontal launch velocity which makes the satellite escape earth's gravitational attraction are interrelated by

(a) $\upsilon_2 = 2\,\upsilon_1$ (b) $\upsilon_2 = \frac{\upsilon_1}{\sqrt{2}}$

(c) $\upsilon_2 = \sqrt{2}\,\upsilon_1$ (d) $\upsilon_2 = 2\sqrt{\upsilon_1}$

28. For orbital velocity between the first orbital velocity (υ_1) and the second orbital velocity (υ_2), the satellite orbit would

(a) be circular (b) be elliptical

(c) have zero eccentricity (d) be eccentric

(e) both (a) and (c) (f) both (b) and (d)

29 The first orbital velocity for launching a satellite at a given height above the surface of earth turns out to be 6 km/s If the said satellite is launched with a horizontal velocity of 8 km/s, the satellite orbit would be

(a) circular and eccentric (b) elliptical and eccentric

(c) circular (d) elliptical

30. The satellite orbit that is highly inclined, elliptical and eccentric is the
    (a) Molniya orbit (b) geostationary orbit
    (c) geosynchronous orbit (d) sub synchronous orbit
    (e) both (a) and (b) (f) both (b) and (c)
31. One of the following is a standard payload of any meteorological satellite
    (a) Very High Resolution Radiometer (VHRR)
    (b) Return Beam Vidicon (RBV)
    (c) C-band transponder
    (d) Optical telescope
    (e) Retarding Potential Analyser (RPA)
32. A payload that is invariably found on all communication satellites is the
    (a) optical telescope (b) VHRR
    (c) transponder (d) vidicon Camera
33. The multiple satellite access technique suitable only for digital transmissions is the
    (a) Time Division Multiple Access (TDMA)
    (b) Frequency Division Multiple Access (FDMA)
    (c) Code Division Multiple Access (CDMA)
    (d) Both (a) and (b)
34 The commonly used multiple access technique that suffers from the disadvantage of likelihood of intermodulation distortion is
    (a) Time Division Multiple Access (TDMA)
    (b) Frequency Division Multiple Access (FDMA)
    (c) Code Division Multiple Access (CDMA)
    (d) Packet Access
35 The commonly used multiple access technique that has very stringent timing and synchronising requirements for the earth station is the
    (a) Code Division Multiple Access (CDMA)
    (b) Frequency Division Multiple Access (FDMA)
    (c) Time Division Multiple Access (TDMA)

(d) Both (a) and (b)

36. The minimum number of geostationary satellite needed for uninterrupted global coverage is

(a) 3 (b) 4 (c) 1 (d) 2

37. With reference to satellite orbit, Apogee is the

(a) highest point in the orbit

(b) lowest point in the orbit

(c) point in the parking orbit

(d) name given to the boost motor that puts the satellite in the right parking slot

38. With reference to satellite orbit, Perigee is the

(a) point in an intermediate orbit

(b) highest point in the orbit

(c) lowest point in the orbit

(d) none of these

39. In a circular geostationary orbit in the equatorial plane,

(a) the apogee equals the perigee

(b) the apogee is twice the perigee

(c) the perigee is twice the apogee

(d) none of these

40. The satellite series from ISRO (India) meant for earth observation applications is the

(a) SROSS-C series (b) INSAT-2 series

(c) IRS-series (d) INSAT-1 series

41. The satellite series developed by ISRO (India) for carrying out scientific studies is the

(a) SROSS-C satellite series (b) IRS series

(c) INSAT-2 series (d) LANDSAT series

42 The value of 'g' in the microgravity environment typically available in space stations is of the order of

(a) $10^{-6}\,g$ (b) $10^{-4}g$ (c) $10^{-12}g$ (d) zero

43. When a satellite of mass (m) is orbiting earth at a height (') from the surface of earth with a velocity (v), then the centri-

force acting on the satellite away from the center of the earth having a mean radius of (R) is given by

(a) mv^2/h (b) $mv^2/(R+H)$

(c) $mv/(R+h)$ (d) mv^2/R

44. When a satellite of mass (m) is orbiting earth at a height (h) from earth's surface with a velocity (v), then the centripetal force due to gravitational attraction of the earth is given by (Assume 'G' as the gravitation constant and 'M' as the mass of earth)

(a) $\frac{GMm}{(R+h)^2}$ (b) $\frac{GM}{(R+h)}$

(c) $\frac{GMm}{R^2}$ (d) $\frac{GMm}{4\pi(R+h)^2}$

45 For an eccentric elliptical orbit with eccentricity (e) and semi-major axis (a), the apogee point distance from the center of earth having a radius of (R) is given by

(a) $r_a = a(1+e)$

(b) $r_a = a(1-e)$

(c) $r_a = a(1+e)/R$

(d) $r_a = aR/(1+e)$

46 For an eccentric elliptical orbit with semi-major axis (a) and eccentricity (e), the perigee point distance from the center of earth having a radius of (R) is given by

(a) $r_p = a(1-e)/R$

(b) $r_p = a(1-e)$

(c) $r_p = a(1+e)$

(d) $r_p = a\,R/(1-e)$

47 If the apogee distance from earth's center is eight times the perigee distance from earth's center, the orbit eccentricity is approximately

(a) 0 12 (b) 0 78

(c) 0 4 (d) 0 6

48 If the escape velocity at a hight of (h) above earth's surface is 10 Km/s, then the escape velocity at a height (4h) above the earth's surface would be

(a) 5 Km/s (b) 20 Km/s

(c) 2.5 Km/s (d) 40 Km/s

49. The most commonly employed analog modulation technique in satellite communication is the

(a) Amplitude Modulation (AM)

(b) Frequency Modulation (FM)

(c) Pulse Amplitude Modulation (PAM)

(d) Pulse Width Modulation (PWM)

50. PCM system is used in satellite communication for transmission of

(a) television signals (b) speech signals

(c) telegraph signals (d) none of these

51. Earth station figure-of-merit is defined as

(a) $10 \log\left(\frac{G}{T}\right)$ (b) $10 \mathrm{L_n}\left(\frac{G}{T}\right)$

(c) $10 \log GT$ (d) $20 \log\left(\frac{G}{T}\right)$

52. An empirical relationship that gives an idea as regards free space attenuation of RF signals as a function of frequency (f) and distance (d) is

(a) $20 \log_{10} f + 20 \log_{10} d$

(b) $20 \log_{10} (d/t)$

(c) $32.5 + 20 \log_{10} f + 20 \log_{10} d$

(d) $32\ 5 + 20 \mathrm{Ln} f + 20 \mathrm{Ln} d$

53 When the orbit eccentricity (e) equals zero, the orbit is

(a) a parabola (b) a hyperbola

(c) elliptical (d) circular

54. When the orbit eccentricity (e) is greater than zero but less than 1, the orbit is

(a) an ellipse (b) a circle

(c) a parabola (d) a hyperbola

55. When the orbit eccentricity equals 1, the orbit takes the i' of

(a) an ellipse (b) a parabola

(c) a hyperbola (d) circle

56. An eccentricity figure of greater than unity would imply that
 (a) the satellite orbit becomes elliptical
 (b) the satellite orbit becomes parabolic
 (c) the satellite escapes from the orbit
 (d) none of these

57. The angular velocity (υ) of a satellite at a height (H) from the surface of earth with a mean radius of (R) is given by
 (a) $\upsilon = R\sqrt{\frac{g}{(R+H)}}$ (b) $\upsilon\sqrt{\frac{g}{R+H)}}$
 (c) $\upsilon = \frac{R_g}{\sqrt{(R+H)}}$ (d) $\upsilon\sqrt{\frac{GM_m}{(R+H)}}$

58. The orbit of a geostationary satellite with an orbital velocity of approximately 3 km/s is slightly inclined at 2° to equatorial plane. The magnitude of the velocity impulse required to be given perpendicular to orbital plane to correct the orbit inclination is equal to (Given that sin 2° = 0.035, cos 2° = 0.999)
 (a) 105 m/s (b) 3 km/s
 (c) indeterminate (d) none of these

59. The earth coverage angle for a geostationary satellite at an altitude of 42000 km from center of earth for a 0° earth station elevation would be (assume earth's radius = 6370 km)
 (a) $2\tan^{-1} 0.15$ (b) $\cos^{-1} 0.15$
 (c) $2\sin^{-1} 0.15$ (d) $\sin^{-1} 0.15$

60. The spread spectrum communication techniques are used in one of the following multiple access methods in satellite communication
 (a) Time Division Multiple Access (TDMA)
 (b) Frequency Division Multiple Access (CDMA)
 (c) Code Division Multiple Access (CDMA)
 (d) Random Access

61. The multiple access technique that is particularly suitable fo[r] communication satellites with military applications is
 (a) TDMA (b) FDMA

(c) CDMA (d) Random access

62. Mark the wrong statement

   (a) an inclined polar orbit can never be a geosynchronous orbit

   (b) All geostationary orbits are geosynchronous orbits whereas all geosynchronous orbits are not geostationary orbits

   (c) Molniya orbit is popular with Russian communication satellites

   (d) A spin stabilised satellite uses a simple technique for stabilisation or attitude control but large number of solar cells whereas a body stabilised satellite uses a very complex stabilisation mechanism but a fewer solar cells.

63 When a geostationary satellite is launched, it is first launched into a low earth orbit from where the orbit is boosted to another transfer orbit which is usually elliptical and eccentric. With another manoeuvre, the elliptical orbit is transformed to a geostationary circular orbit. If the apogee point in the elliptical transfer orbit is the same as the apogee point in the final circular geostationary orbit, then the velocity of the satellite at the apogee point in the circular orbit is

   (a) equal to the velocity at the apogee point in the elliptical orbit

   (b) less than the velocity at the apogee point in the elliptical orbit

   (c) greater than the velocity at the apogee point in the ellipitical orbit

   (d) at least four times the velocity at the apogee point in the elliptical transfer orbit

64. With reference to Q-63, if (a) is the semi-major axis of elliptical transfer orbit and (r) is the distance of a given point on the orbit from the centre of earth, then the orbital velocity of the satellite at that point is given by $(\mu = GM)$

   (a) $v = \sqrt{\left(\frac{2\mu}{r} - \frac{\mu}{a}\right)}$ (b) $v = \left[\frac{2\mu}{r} - \frac{\mu}{a}\right]$

   (c) $v^2 = \left[\frac{\mu}{r} - \frac{1}{a}\right]$ (d) $\sqrt{\frac{\mu}{r+a}}$

65 The orbital velocity at the apogee point in an eccentric orbit increases when the elliptical orbit is

circular orbit with apogee point remaining the same. This increment in velocity is the minimum when

(a) elliptical orbit plane is inclined at 45° to the circular orbit plane

(b) elliptical orbit plane is at right angles to the circular orbit plane

(c) elliptical orbit and circular orbit are in the same plane

(d) none of these

66. Molniya orbit serves the purposes of a geosynchronous orbit for high latitude regions. The number of satellites usually required at different phases of the same Molniya orbit to provide uninterrupted service to a given area is

(a) 3 (b) 6 (c) 1 (d) 4

67. Highly inclined, highly eccentric elliptical Molniya orbit has a perigee of 500 km and an apogee of 40,000 km above the surface of earth, then the orbital velocity at the apogee would approximately be (Assume earth's radius = 6578 km).

(a) 1.5 km/s (b) 150 m/s

(c) 15 km/s (d) 3 km/s

68. For the orbit in Q-67, the semi-major axis of the elliptical orbit is (Assume radius of earth = 6578 km)

(a) 26828 km (b) 20,000 km

(c) 22500 km (d) indeterminate from given data

69. For the orbit in Q-67, the semi-minor axis of the elliptical orbit is (Assume radius of earth = 6578 km)

(a) 250 km (b) 20,000 km

(c) 500 km (d) 18,125 km

70. The eccentricity of an elliptical orbit with the apogee point at 43,000 km and the perigee point at 7000 km from centre of earth is

(a) 0.72 (b) 0 16

(c) 0.45 (d) indeterminate from given data

71. In an eccentric elliptical orbit, the distance between centre of ellipse and centre of earth is 15,000 km. If the orbit eccentricity is 0.6, the semi-major axis of the orbit equals

(a) 9000 km (b) 25,000 km

(c) 6000 km (d) 37,500 km

72. For the orbit in Q-71, the distance of apogee point from earth's centre is

(a) 50,000 km (b) 25,000 km

(c) 40,000 km (d) 10,000 km

73. For the orbit in Q-71, the distance of perigee point from the centre of earth is

(a) 10,000 km (b) 500 km

(c) 7500 km (d) 15,000 km

74 The satellite in which the antennas are mounted on a de-spun platform is the

(a) geostationary satellite

(b) sun synchronous satellite

(c) spin stabilised satellite

(d) 3-axis body stabilised satellite

75. In a spin stabilised geostationary satellite, the spin axis is

(a) perpendicular to the orbital plane

(b) in the plane of the orbit

(c) inclined at 45° to the orbital plane

(d) none of these

76. The satellite in which the solar cells are mounted on panels external to the space craft body, allowing them to be oriented towards the sun, is the

(a) communication satellite

(b) direct broadcast satellite

(c) 3-axis body stabilised satellite

(d) spin stabilised satellite

77. Satellite (S_1) and (S_2) are orbiting in two different equatorial circular orbits. The radius of S1-orbit is four times the radius of S2-orbit. The orbital period of S-1 orbit will therefore be

(a) 4 times the orbital period of satellite S2

(b) 8 times the orbital period of satellite S2

(c) twice the orbital period of satellite S2

(d) same as the orbital period of satellite S2

78. The satellite orbit is termed as a retrograde orbit when its angle of inclination

(a) becomes 45° (b) exceeds 90°

(c) zero (d) becomes 90°

79. With reference to the solar eclipses caused to a communication satellite by the earth and the moon,

(a) the eclipse due to earth is of a smaller duration

(b) the eclipse due to earth affects the satellite much more than the eclipse due to moon

(c) while the eclipse due to earth is harmful, the one due to moon is useful

(d) while the eclipse due to earth is useful, the one due to moon is harmful

80. With reference to transponder capacity utilisation in case of TDMA and FDMA techniques,

(a) the capacity utilisation is almost 100% irrespective of number of accesses in TDMA

(b) the capacity utilisation can never be 100% in FDMA

(c) the capacity utilisation is 100% in TDMA for a single access only

(d) none of these

81 The earth station antenna is fed from a power amplifier producing 2 KW at its output. If the waveguide joining the amplifier output and the antenna input has a loss of 2 dB and the antenna has a gain of 51 dB at the operating uplink frequency, the EIRP of the antenna is

(a) 82 dB (b) 49 dB

(c) 86 dB (d) indeterminate from given data

82. For an antenna with a circular aperture, if the operating frequency is doubled, then for the same antenna gain, the antenna diameter

(a) can be reduced to one-fourth.

(b) can be reduced to half

(c) can be increased to four times

(d) can be reduced to one-third

83. A satellite earth station antenna has a gain of 10^6 and a noise temperature of 100°K. The earth station (G/T) in dB per Kelvin is

(a) 40 dB/K (b) 80 dB/K

(c) indeterminate (d) none of these

84. A typical satellite earth station has, on its receive side, the antenna followed by a low noise amplifier and a down converter in the same order. The earth station (G/T) ratio in dB/K as referred to the input of low noise amplifier is 50 dB/K. If the down converter equivalent noise temperature is 10000 K, the system (G/T) ratio as referred to input of down converter would be

(a) 10 dB/K (b) 60 dB/K

(c) 50 dB/K (d) none of these

85. A satellite earth station has dual down converter. If the down link frequency is 46 Hz and the IF is 70 MHz, then sum of first and second local oscillator frequencies would be

(a) 3.93 GHz (b) 4.07 GHz

(c) 8.14 GHz (d) none of these

Incomplete Statements

1. "An artificial satellite at the correct distance from earth would make one revolution every 24 hours and thus would remain stationary above the same spot." This statement was made by a famous British science fiction writer in 1945 in the journal Wireless World. His name was____________.

(Arthur C. Clarke, Johannes Kepler, Issac Newton)

2. "The line joining the center of earth and the satellite sweeps over equal areas in equal intervals of line." This is one of the famous ____________.

(Kepler's laws, Newtonian laws, Galilean laws)

3. The earth observation satellites are placed in________ orbits.

(sun synchronous, geosynchronous, geostationary)

4. The orbital inclination correction manoeuvre is carried ____________.

(midnight, nodal points, regular intervals)

5. The manoeuvre to circularize the orbit and make it geostationary while it is in the intermediate transfer orbit is always carried out at the

(apogee point, perigee point, nodal point)

6. The maximum daily eclipse duration experienced by a satellite is at ______.

(spring and autumn equinoxes, summer and winter solstices)

7. The angle of inclination between the earth's equatorial plane and the direction of sun at equinoxes is ______.

(0°, 45°, 90°)

8. The angle of inclination between the earth's equatorial plane and the direction of sun at summer solstice is ______.

(0°, 90°, 23.4°)

9. The duration of a sidereal day is ______.

(24 days, 23 days 46 minutes, 23 days 56 minutes 9 seconds)

10. In a satellite communication link, if the allowable minimum angle of elevation of the earth station antenna increases, the satellite's coverage area ______. (increases too, decreases, remains unchanged)

11. A larger diameter dish antenna, operational frequency remaining same, Produces a ______ beamwidth.

(narrower, wider)

12. The dish antenna that has a higher pointing accuracy, lower noise temperature and flexibility in feed design is the ______.

(paraboloid antenna, cassegrain antenna)

13 In a cassegrain antenna, the hyperboloid subreflector is so placed as to have the feed phase center located at ______ of the subreflector.

(real focal point, virtual focal point)

14. In a given earth station antenna, the antenna aperture efficiency has two predominant components; main reflector illumination efficiency of 0.9 and spill-over efficiency of 0.8. The overall efficiency would be ______.

(0.72, 0.85)

15. The semi-major axis of a certain elliptical satellite orbit is 20,000 km. The apogee and perigee distances from earth's center of another elliptical satellite orbit are both twice their counterparts in the first elliptical orbit In that case, the semi-major axis of the second orbit would be ________ .

    (10,000 Km, 40,000 Km)

16 If the perigee and apogee distances from earth's center in an elliptical eccentric orbit are both changed by factor (K), the orbit eccentricity would ________ .

    (remain unaffected, change by the same factor K, change by a factor 2 K)

17. In an elliptical satellite orbit, the center of earth lies________.

    (at one of foci of ellipse, at a point on its semi-minor axis)

18 The semi-minor axis of the ellipse of an elliptical satellite orbit is given by ________ .

    (average of the apogee and perigee distances, geometric mean of the apogee and perigee distances)

19. The semi-major axis of the ellipse of an elliptical orbit is given by ________ .

    (geometric mean of apogee and perigee distances, arithmetic mean of apogee and perigee distances)

20. The semi-minor axis and the perigee distance from earth's center of an elliptical orbit are respectively 16000 Km and 8000 Km. The apogee distance from earth's center would be ________ .

    (32000 Km, 24000 Km, 64000 Km)

21 In a satellite link, the carrier saturation EIRP at the satellite is 1000 watts. If the input and output back-offs of the satellite TWTA are 6 dB and 4 dB respectively, the carrier EIRP would be ________ .

    (24 dBW, 26 dBW, 20 dBW)

22. If for the data given in the above statement, the satellite EIRP for the retransmitted carrier is 40 dBW, the satellite saturation EIRP for the retransmitted carrier would be ________ .

    (36 dBW, 44 dBW, 50 dBW)

23. In a satellite link, the uplink and downlink carrier to n ratios are 30 dB and 20 dB respectively. The overall link to noise ratio would be________ .

(50 dB, 10 dB, 12 dB, 19.6 dB)

24. The multiple satellite access system that suffers from presence of intermodulation products is ________.

    (FDMA, TDMA)

25. The multiple access system in which each earth station has the entire transponder bandwidth available to it is ________.

    (FDMA, TDMA)

Identify TRUE and FALSE Statements

1. All geostationary satellites are geosynchronous while the reverse is not true.
2. The velocity of the satellite at a certain point in the orbit is the same for elliptical and circular orbits as long as the point in question is at the same distance from center of earth
3. The velocity of the satellite at its apogee point is always greater than the velocity at its perigee point.
4. The spin stabilised satellites have a despun platform on which antennas are mounted.
5. The geostationary satellite location is specified in terms of its longitude
6. The earth observation satellites are put in sun synchronous orbits so as to ensure that they receive uninterrupted solar radiation throughout the year.
7. Molniya orbit is the Russian name for a geostationary orbit.
8. The communication satellites with extendible solar sails are three-axis stabilised.
9. The communication satellites with body mounted solar calls are spin stabilised.
10. India's INSAT series satellites are multipurpose satellites combining communication, TV broadcast, weather forecast and earth observation roles.
11. The idea of geostationary satellite was first expressed by Johannas Kepler.
12. The satellite velocity depends upon the thurst with which it is launched and is constant for a given orbit.

13. Transponder is the essential instrumentation payload of all satellites.
14. The escape velocity at a height (H) above earth's surface would be higher than the escape relocity at a height (2 H)
15. Only geostationary satellites can be used for international communication and TV broadcast purposes.
16. A 6 GHz/4 GHz satellite communication link needs a C-band transponder.
17. The up-link frequency is always higher than the down link frequency.
18. A radiometer would be found on a meteorological satellite.
19. The satellite velocity is minimum at the perigee point
20. The spot beam satellite antennas produce a circular cross-section on the ground.
21. The earth station antennas accessing geostationary satellites needs to continuously track the satellites at a rate equal to earth's rotation.
22. Three geostationary satellites spaced 120° apart can provide full global coverage including polar regions.
23. A rocket carrying a geostationary satellite is fired from a station with a latitude of 4°N. The satellites's orbital plane would be inclined at least 4° to equatorial plane in the absence of any inclination correction manoeuvre.
24. In a spin stabilised geostationary satellite, the spin axis is perpendicular to the geographical polar axis.
25. In a two-way satellite communication link such as an international telephone communication link, the total round trip propagation delay is about 480 ms.

ANSWERS

Multichoice Questions

1 (d)	2. (a)	3 (c)	4 (c)	5. (b)
6. (b)	7 (d)	8. (a)	9 (a)	10.(b)
11 (c)	12. (a)	13 (b)	14. (c)	15. (c)
16 (d)	17 (d)	18. (c)	19. (g)	20. (b)
21 (c)	22 (c)	23 (d)	24 (c)	25 (a)
26 (b)	27 (c)	28 (f)	29 (b)	30 (a)
31 (a)	32 (c)	33. (a)	34. (b)	35. (c)
36 (a)	37 (a)	38. (c)	39 (a)	40 (c)
41 (a)	42. (b)	43 (b)	44. (a)	45 (a)
46 (b)	47 (b)	48 (a)	49. (b)	50 (b)
51. (a)	52. (c)	53 (d)	54 (a)	55. (b)
56 (c)	57. (a)	58 (a)	59 (c)	60 (c)
61 (c)	62. (a)	63. (c)	64 (a)	65. (c)
66 (a)	67. (a)	68 (a)	69. (d)	70. (a)
71. (b)	72. (c)	73. (a)	74. (c)	75. (a)
76. (c)	77. (b)	78 (b)	79. (b)	80. (a)
81. (a)	82 (b)	83. (a)	84 (c)	85. (a)

Incomplete Statements

1. Arthur C. Clarke 2. Kepler's laws 3. sun synchronous 4 nodal points 5. apogee point 6 spring and autumn equinoxes 7 0° 8. 23 4° 9. 23 days, 56 minutes, 9 seconds 10. decreases 11. narrower 12. cassegrain antenna 13. real focal point 14 0.72 15 40000 Km 16. remain unaffected 17. at one of foci of ellipse 18 geometric mean of perigee and apogee distances 19. arithmetic mean of perigee and apogee distances 20. 32000 Km 21. 24 dBW 22 44 dBW 23. 19.6 dB 24. FDMA 25. TDMA

TRUE and FALSE Statements

1. True	2. False	3. False	4. True	5. True
6. False	7. False	8 True	9. True	10. False
11. False	12. False	13. False	14 True	15. False
16. True	17. True	18 True	19 False	20. False
21. False	22. False	23. True	24. False	25 True.

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